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April 2026

Concrete solutions

Cutting carbon emissions from this vital building material

Clean potential Harnessing the power of commercial laser fusion

Challenging life Meet the man who kept Ethiopian physics alive

Career journey Natasha Khan on her work as a nuclear safety engineer

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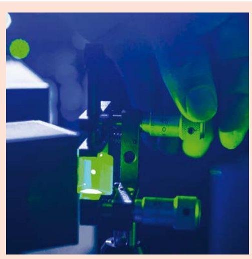


Physics World Live

This year's series of online panel discussions kicks off on 30 April with Physics World Live: Quantum Metrology.

physicsworld.com/p/physics-world-live

News & Analysis

‘Deep concern’ over UK physics

Heads of almost 60 physics departments sign letter to UK science minister Patrick Vallance saying UK funding cuts are causing “reputational risk”, as **Michael Banks** reports

The heads of university physics departments in the UK have published an open letter expressing their “deep concern” about funding changes announced late last year by UK Research and Innovation (UKRI), the umbrella organization for the UK’s research councils. Addressed to science minister Patrick Vallance, the letter says the cuts are causing “reputational risk” and calls for “strategic clarity and stability” to ensure that UK physics can thrive. It has so far been signed by 58 people who represent 45 different universities, including Birmingham, Bristol, Cambridge, Durham, Imperial College, Liverpool, Manchester and Oxford.

The letter says that the changes at UKRI “risk undermining science’s fundamental role in improving our prosperity, health and quality of life, as well as delivering sustainable growth through innovation, productivity and scientific leadership”. The signatories warn that the UK’s international standing in physics is “a strategic asset” and that areas such as particle physics, astronomy and nuclear physics are “especially important”.

The decision by the heads of physics to write to Vallance comes in the wake of UKRI stating in December that it will be adjusting how it allocates government funding for scientific research and infrastructure. The Science and Technology Facilities Council (STFC), which is part of UKRI, stated that projects would need to be cut given inflation, rising energy costs as well as “unfavourable movements in foreign exchange rates” that have increased the STFC’s annual costs by over £50m a year.

The STFC noted that it would need to reduce spending from its core budget by at least 30% from 2024/2025 levels while also cutting the number of projects financed by its infrastructure fund. The council has already said two UK national facilities – the Relativistic Ultrafast Electron Diffraction and Imaging facility and a mass spectrometry centre dubbed CMASS – will now not be prioritized. In addition, two international particle-physics projects will not be supported: a UK-led upgrade to the LHCb experiment at CERN as well as a contribution to the Electron-Ion Collider at the Brookhaven National Laboratory that is currently being built.

CERN/Maximilien Brice

Cause for concern The UKRI’s total budget is relatively stable at £38.6bn over the four years to 2030, but will include deprioritizing a UK-led upgrade to the LHCb experiment at CERN.

Constraining these areas risks weakening the very talent pipeline on which the UK’s innovation economy depends

“Abrupt” and “damaging”

Philip Burrows, director of the John Adams Institute for Accelerator Science at the University of Oxford, who is one of the signatories of the letter, told *Physics World* that the cuts are “like buying a Formula-1 car but not being able to afford the driver”. Burrows admits that the STFC has been hit “particularly hard” by its flat-cash settlement, given that a large fraction of its expenditure pays the UK’s subscriptions to international facilities and operating the UK’s flagship national facilities. But because most of the rest of the STFC’s budget supports scientists to do research at those facilities, he is concerned that the funding cuts will fall disproportionately on the science programme.

“Constraining these areas risks weakening the very talent pipeline on which the UK’s innovation economy depends,” the letter states. “Fundamental physics also delivers substantial public engagement and cultural impact, strengthening public support for science and reinforcing the UK’s reputation as a global scientific leader.” The signatories also say they are “particularly concerned” about the UK’s capacity to lead the scientific exploitation of major international projects. “An abrupt pause in funding for key international science programmes risks damaging UK researchers’ competitive advantage into the 2040s,” they note.

The letter calls on the government to work with UKRI and the STFC to “stabilize” curiosity-driven grants for physics within the STFC “at a minimum of flat funding in real terms” as well as protect postdocs, students and technicians from the cuts. It also calls on the UK to develop a long-term strategy for infrastructure and call on the government to address facilities cost pressures through “dedicated and equitable mechanisms so that external shocks do not singularly erode the UK’s research base in STFC-funded research areas”.

The news comes as Michele Dougherty formally stepped down from her role as IOP president. Dougherty, who also holds the position of executive chair of the STFC, had previously stepped back from presidential duties on 26 January due to a conflict of interest. Paul Howarth, who has been IOP president-elect since September, has now become IOP president.

Michael Banks is news editor of *Physics World*

Anthony Leggett dies aged 87

Michael Banks looks at the British-American theorist's Nobel-prize-winning contributions to our understanding of superfluidity

The theoretical physicist Anthony Leggett, who was an honorary fellow of the Institute of Physics, died on 8 March at the age of 87. Leggett shared the 2003 Nobel Prize in Physics with Alexei Abrikosov and Vitaly Ginzburg for their "pioneering contributions to the theory of superconductors and superfluidity".

Born on 26 March 1938 in London, UK, Leggett graduated in *literae humaniores* (classical languages and literature, philosophy and Greco-Roman history) at the University of Oxford in 1959. While philosophy was Leggett's strongest subject, he did not envisage a career as a philosopher because he felt that the subject depended more on turns of phrase than objective criteria. As part of an experiment at Oxford to see if it was possible to convert a classicist with minimal qualifications in maths and science into a physicist, Leggett also earned a degree in physics in 1961.

Leggett then embarked on a DPhil in physics, which he completed at Oxford in 1964, followed by postdocs at the University of Illinois Urbana-Champaign in the US and Kyoto University, Japan. In 1967 he moved back to the UK, spending the next 15 years at Sussex University. It was at Sussex that he carried out his Nobel-prize-winning work on the theory of superfluidity – the ability of a fluid to flow without viscosity.

Superfluidity in helium-4 was discovered in the 1930s, and in the 1960s several theorists predicted that helium-3 might also be a superfluid. However, the two forms of helium are fundamentally different. Helium-4 atoms are bosons and can all condense into the same quantum ground state at low enough temperatures – an essential feature of both superfluidity and superconductivity. Helium-3 atoms, on the other hand, are fermions and the Pauli exclusion principle prevents them from entering such a quantum state.

Electrons, which are also fermions, overcome this problem by forming Cooper pairs as described by the BCS theory of superconductivity that was developed in the mid-1950s by John Bardeen, Leon Cooper and Robert Schrieffer. Theorists predicted that helium-3 atoms could do something similar and in 1972 superfluidity in helium-3 was finally observed at Cornell University – a feat that earned David Lee, Douglas Osheroff and Robert Richardson the 1996 Nobel Prize in Physics. Yet many of the results puzzled theorists. In particular there were three different superfluid phases, and the results of nuclear magnetic resonance experiments on the samples could not be explained.


University of Illinois Urbana-Champaign

Low-temperature pioneer Anthony Leggett made crucial contributions to the theory of superfluidity in the 1970s.

Leggett showed that these results could be explained by the spontaneous breaking of various symmetries in the superfluid and for the work he was awarded a third of the 2003 Nobel Prize in Physics, with Abrikosov and Ginzburg being honoured for their work on type-II superconductors.

America bound

In 1983 Leggett moved to the University of Illinois at Urbana-Champaign where he remained for the rest of his career until retiring in 2019. There he focused on problems in high-temperature superconductivity, superfluidity in quantum gases and the fundamentals of quantum mechanics. In 2004 he was appointed Knight Commander of the Order of the British Empire (KBE) "for services to physics". In 2023 the Institute for Condensed Matter Theory at the University of Illinois at Urbana-Champaign was renamed the Sir Anthony Leggett Institute. As well as the Nobel prize, Leggett won many other awards including the 2002 Wolf Prize for physics. He also published two books: *The Problems of Physics* (Oxford University Press, 1987) and *Quantum Liquids* (Oxford University Press, 2006).

Peter McClintock from Lancaster University, who has carried out work in superfluidity, says he is "very sad" to hear the news. "[Leggett] was a brilliant physicist whose genius was to comprehend underlying mechanisms and processes and explain their physical essence in comprehensible ways," says McClintock. "My dominant memory is of the discovery of the superfluid phases of helium-3 and of the way in which [Leggett] was able to interpret each new item of experimental information and slot it into a nascent theoretical framework to build up a coherent picture of what was going on – while always enumerating the remaining loose ends and possible alternative explanations."

James Sauls, a theorist at Louisiana State University, says that Leggett made discoveries in several areas of physics such as the foundations of quantum mechanics, quantum tunnelling in amorphous glasses and superconducting devices as well as the theory of heat transport at ultralow temperatures. "Leggett's contributions to quantum mechanics and low-temperature physics are remarkable and enduring," adds Sauls. "[Leggett's] style in theoretical physics was unique in its clarity and originality."

In a statement, Makoto Gonokami, president of the RIKEN labs in Japan, also expressed that he is "deeply saddened" by the news and that Leggett had "provided warm support for researchers in Japan" through his many trips to the country. "Leggett made pioneering contributions to our understanding of how quantum mechanics manifests itself in macroscopic matter [and] his theoretical work on superfluid helium-3 provided profound insights into quantum order in strongly interacting fermionic systems," notes Gonokami. "His work significantly advanced the study of quantum condensed matter and macroscopic quantum coherence."

Michael Banks is news editor of *Physics World*

A century of physics at Tsinghua

Wenhui Duan, head of physics at Tsinghua University in Beijing, talks to Michael Banks about this leading Chinese institution's plans for the future in its centenary year

Can you tell us about your career in physics?

My academic path studying physics at Tsinghua University began in 1981 where I completed a bachelor's and a master's before earning a PhD in 1992. I then did a postdoc at the Central Iron & Steel Research Institute in Beijing before returning to Tsinghua University in 1994 as a faculty member in the physics department.

Have you always studied and worked in China?

During my time at Tsinghua I carried out two research visits abroad: at the University of Minnesota from 1996 to 1999; then at the University of California, Berkeley, from 2002 to 2003.

What is your research focus?

My career has been centred on developing theoretical computational methods to understand, predict and design the physical properties of materials from the microscopic level of atoms and electrons. My work is an attempt to use a "computational microscope" to probe the fundamental nature of materials and sketch blueprints for new ones.

Can you provide some examples?

One is in the theoretical study of topological quantum materials. We have performed theoretical work predicting the potential for the quantum spin Hall effect in 2D systems and we have explored new states of matter such as topological semimetals. Another avenue of research is on the physics of low-dimensional and artificial microstructures.

Are you using AI in this endeavour?

Yes. A significant recent focus is pioneering the integration of artificial intelligence with computational materials science. We are developing deep-learning models that are compatible with mainstream computational frameworks to increase the efficiency of simulating complex material systems and accelerate the discovery of new materials.

Tsinghua University

Looking ahead Wenhui Duan says that artificial intelligence will be an important factor for physics in the coming decades.

What areas of physics research is Tsinghua active in?

Our research can be mainly outlined as three core directions. The first is condensed-matter physics, which has historically been one of our largest and most prominent areas. Experimentally we work in areas such as topological quantum materials, high-temperature superconductivity, two-dimensional systems, and novel magnetic phenomena. Theoreticians, including my group, focus on predicting new quantum states and understanding complex electronic behaviours using first-principles calculations and model analysis.

What about the other two areas?

The second area is atomic, molecular and optical physics. Key topics include ultracold atoms for quantum simulation of complex many-body problems, quantum optics and quantum communication, and precision measurement science. The other area is nuclear physics and particle physics, where we work in major international collaborations such as the Large Hadron Collider. Besides these core directions, our research is also focused on programmes in astrophysics/cosmology and in biophysics. The emergent field of quantum-information science also connects nearly all these areas, making it a defining feature of our current research environment.

Are there some areas of physics that Tsinghua might increase its efforts in?

One is the integration of AI and machine learning with fundamental physics research. In my own field of computational materials science, we are already using AI to accelerate the discovery of new quantum materials and predict complex properties with unprecedented speed. This approach should be expanded and deepened across the department – from using AI to analyse data from particle colliders and gravitational-wave detectors, to developing new algorithms for quantum many-body problems and astrophysical simulations.

What other priorities do you have?

We must also intensify our efforts in the development and application of quantum technologies. We already have excellent groups in quantum information, quantum optics and quantum materials so the next step is to combine these strengths towards the engineering of functional quantum systems.

What international collaboration is Tsinghua involved in?

Our researchers are embedded in several "big science" projects such as the XENON collaboration for direct dark-matter detection, particle physics experiments like ATLAS, CMS and FASER at CERN, as well as the LIGO collaboration in gravitational-wave astronomy.

What about those closer to home?

Domestically, we work with the Institute of Physics at the Chinese Academy of Sciences and the Beijing Academy of Quantum Information Sciences, particularly in areas like condensed

matter and quantum science. We also value industry partnerships, a notable example being our long-standing collaboration with Foxconn, which formed the joint Foxconn Nanotechnology Center within our department.

How many students and staff are there in Tsinghua's physics department?

We have an academic community of more than 900 people: 85 faculty members, around 100 staff members, 420 graduate students and 320 undergraduate students.

How many foreign staff and students do you have?

We currently have four foreign professors together with 11 international undergraduates and five international PhD candidates – from Malaysia, Germany, Belarus, Russia and Iran.

Would you like to see these numbers increase?

Yes, but my emphasis is more on qualitative enhancement than just quantitative increase. A more diverse international community brings essential perspectives that challenge assumptions, spark innovation and elevate our collective work to a global standard. We are working to create an even more welcoming and supportive environment through dedicated discussions on internationalization, fostering research collaborations and hosting global conferences.

What is Tsinghua like as a place to work?

First, Tsinghua's strengths across science and engineering create a natural incubator for interdisciplinary work. Second is the balance of academic freedom and responsibility. The university provides substantial intellectual freedom and long-term support, allowing researchers to pursue high-risk, fundamental questions without being bound solely by short-term deliverables. Coupled with this freedom is a profound sense of responsibility to contribute to national and global scientific efforts, an ethos deeply embedded in Tsinghua's tradition. Third is the quality of the students. Mentoring them from promising undergraduates to independent researchers is a core part of the scientific legacy we build here.

How will you be marking the centenary of physics at Tsinghua?

We have a number of activities planned, including an alumni interview series and department exhibitions to visually narrate our history and scientific contributions. We are collaborating with the Chinese Physical Society, the Chinese Academy of Sciences and the National Natural Science Foundation as well as IOP Publishing to publish commemorative special issues throughout the year. There will also be a series of high-level academic forums and lecture series at Tsinghua. The culmination of the year's celebration will be the Centennial Commemoration Conference in September.

> I hope we are known not just for our discoveries, but for building essential research "bridges" that solve big problems

What do you hope for Tsinghua in the coming 100 years?

First, I hope we become the world's leading centre for a new way of doing physics: integrating AI directly into the core of our research cycle. This means moving beyond using AI just as a tool. Second, I hope we are known not just for our discoveries, but for building essential research "bridges" that solve big problems. This means partnering with our engineering schools to turn quantum science into reliable technology as well as with life sciences and environmental science to apply physical principles to global challenges in health and sustainability. We aim to educate students who are not just technically able, but who are also ethically grounded and driven. If we succeed, then Tsinghua Physics will continue to contribute to our understanding of the world. That is the enduring legacy we strive for.

Publishing

Scientists fail to disclose use of AI despite journal mandates

An analysis of more than 5.2 million papers in 5000 different journals has revealed a dramatic rise in the use of artificial intelligence (AI) tools in academic writing across all scientific disciplines, especially physics. However, the findings reveal a big gap between the number of researchers who use AI and those who admit to doing so – even though most scientific journals have policies requiring the use of AI to be disclosed (*Proc. Natl Acad. Sci.* **123** e2526734123).

Carried out by data scientist Yi Bu from Peking University and colleagues, the research looks at papers in the OpenAlex dataset that were published between 2021 and 2025. To assess the impact of editorial guidelines introduced in response to the growing use of generative AI tools such as ChatGPT, they examined journal AI-writing policies, looked at author disclosures and used AI to see if papers had been written with the help of technology.

Shutterstock/Jackie Niam

Help or hindrance? A new analysis finds a rapid increase in the use of AI in scientific writing.

The AI detection analysis reveals that the use of AI writing tools has increased dramatically across all scientific disciplines since 2023. It also finds that 70% of journals have adopted AI policies, which primarily require authors to disclose the use of AI-writing tools.

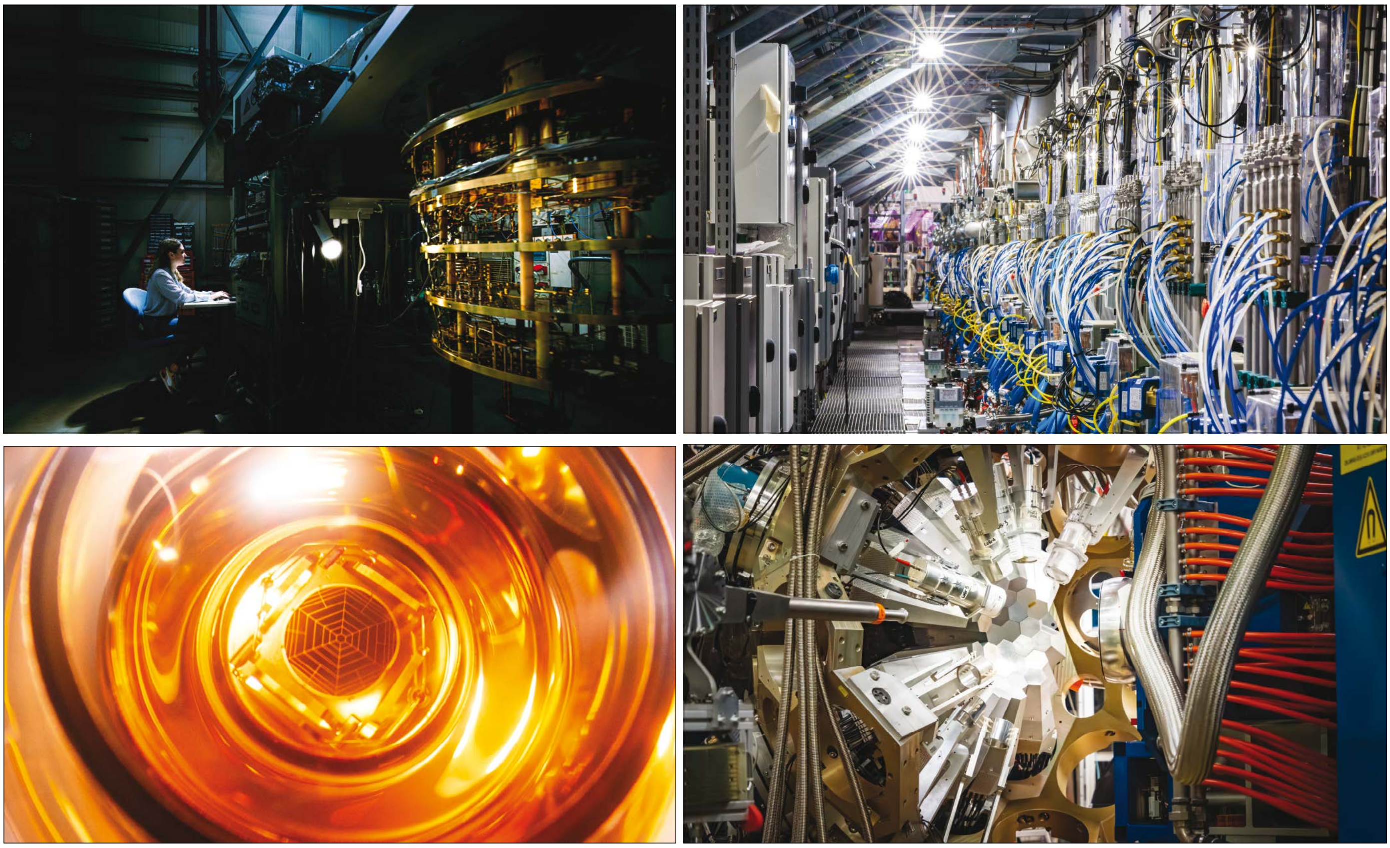
But the new study, which includes a full-text analysis of 75 000 papers published since 2023, reveals that only 76 articles explicitly disclosed the use of AI writing tools. It also finds no significant difference in the use of AI between journals that have disclosure policies and those that do not, which suggests that disclosure requirements are being ignored – what the authors call a "transparency gap".

The study also finds that researchers from non-English-speaking countries are more likely to rely on AI writing tools than native English speakers. Increases in the use of AI writing tools are particularly rapid in journals with high levels of open-access publishing.

The authors now call for a re-evaluation of ethical frameworks to foster responsible AI integration in science. They state that prohibition or disclosure requirements are insufficient to regulate AI use, with their results showing that researchers are not complying with existing policies.
Michael Allen

Global Physics Photowalk winners revealed

Michael Banks examines the images from this year's competition that cast the world's premier particle-physics labs in a new light



Marco Donghia; Yannig Van De Wouwer/GANIL/CNRS; Matteo Monzali; Hugo Pardinilla/CPPM/CNRS

Particle pics (Clockwise from top left) A photograph of the Cryogenic Laboratory for Detectors; the linear accelerator of SPIRAL2; the Advanced Gamma Tracking Array photon detector coupled with PRISMA magnetic spectrometer; a photomultiplier from the KM3NeT/ORCA experiment.

From an image of a detector hunting for signs of dark matter to a picture of a deep-sea neutrino telescope studying astrophysical phenomena, the winning entries for the 2025 Global Physics Photowalk have been announced by the Interactions Collaboration – an international network of particle-physics institutions.

Some 16 labs around the world took part in the event, in which they opened up their labs for a day in 2025 to amateur and professional photographers. Each lab entered its top three images into the global competition and from those 48 images a panel of judges selected their top three photos, while the public also chose their top three favourite images via an online vote held in January.

Marco Donghia's photograph (top left) was awarded first place by the judges. It features a researcher sat in front of the Cryogenic Laboratory for Detectors, which is based at INFN National Laboratories of Frascati. The experiment aims to detect extremely weak and rare signal such as those produced by dark matter.

"Finding out I had won left me speechless," notes Donghia. "The cryostat I photographed is just a few fractions of a degree above absolute zero, yet this recognition filled me with such warmth and emotion that no cryogenic temperature could cool them down."

An image by Yannig Van De Wouwer (top right) of the back of the linear accelerator of SPIRAL2 at the Large Heavy Ion National Accelerator, GANIL, based in Caen, France, won first place in the public vote.

Second place in the judges' competition went to Matteo Monzali for his photo (bottom right) of the Advanced Gamma Tracking Array photon detector coupled with the PRISMA magnetic spectrometer. The experiment is based at the TANDEM-ALPI-PIAVE accelerator complex at INFN National Laboratories in Legnaro.

Third place in the judges' competition (bottom left) went to Hugo Pardinilla's spectacular close-up image of a photomultiplier from the KM3NeT/ORCA experiment, a neutrino telescope currently being installed in the Mediterranean Sea off the coast of Provence, France.

This is the fifth international photowalk following events held in 2010, 2012, 2015 and 2018.

● All 48 images submitted to the 2025 competition can be viewed at interactions.org/photowalk

Michael Banks is news editor of *Physics World*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Research updates

Boost for quantum sensing

"Quantum memories" could make long-baseline optical astronomy with single photon sensitivity a reality, as **Tim Wogan** reports

Quantum-entangled sensors placed over a kilometre apart could allow interferometric measurements of optical light with single photon sensitivity, experiments in the US suggest. While this proof-of-principle demonstration of a theoretical proposal first made in 2012 is not yet practically useful for astronomy, it marks a significant step forward in quantum sensing (*Nature* doi:10.1038/s41586-026-10171-w).

Radio telescopes are often linked together to provide more detailed images with better angular resolution than would otherwise be possible. The Event Horizon Telescope array, for example, performs very long baseline interferometry of signals from observatories on four continents. At shorter wavelengths, however, much weaker signals are often parcelled into higher-energy photons.

According to quantum mechanics, it is possible to create an interferometric image from single photons by recombining their paths at a single detector – provided that their paths are not measured before then. This principle is used in laboratory spectroscopy but in astronomical observations, attempting to transport single photons from widely spread telescopes to a central detector would almost certainly result in them being lost. The baseline of infrared and optical telescopes is therefore restricted to about 300 m.

In 2012, theorist Daniel Gottesman, then at the Perimeter Institute for Theoretical Physics in Canada, and colleagues proposed using a central single source of entangled photons as a quantum repeater to generate entanglement between two detection sites, putting them into the same quantum state. The effect of an incoming photon on this combined state could therefore be measured without having to recombine the paths and collect the photon at a central detector. "In reality, the photon will be in a superposition of arriving at both of the detectors," says Pieter-Jan Stas at Harvard University. "That's where this advantage comes from – you have this photon that is delocalized and arrives at both the left and the right station – so you truly have this baseline that helps you with improving your resolution, but to do this you have to keep the 'which path' information hidden."

iStock/Jian Fan

Coming together Physicists in the US have shown how the phenomenon of quantum entanglement could be used to link optical telescopes over long distances.

The 2012 proposal was not thought to be practical because it required distributing entanglement at a rate comparable with the telescope's spectral bandwidth. In 2019, however, Harvard's Mikail Lukin and colleagues proposed integrating a quantum memory into the system and in the new research, they demonstrate this in practice. The team used qubits made from silicon–vacancy centres in diamond. These can be very long lived because the spin of the centre's electron, which interacts with the photon, is mapped to the nuclear spin, which is very stable.

The researchers used a central laser as a coherent photon source to generate heralded entanglement to certify that the qubits were event-ready. "It's not like you have to receive the space signal to be simultaneous with the arrival of the photon," says team member Aziza Suleymanzade at the University of California, Berkeley. "In our case, we distribute entanglement, and it has some coherence time, and during that time you can detect your signal."

Using two detectors placed in adjacent laboratories and synthetic light sources, the researchers demonstrated photon detection above vacuum fluctuations in fibres over 1.5 km in length. They acknowledge that much work remains before this can be viable in practical astronomy, such as a higher rate of entanglement generation, but Stas says it is "one step towards bringing quantum techniques into sensing".

Yujie Zhang of the University of Waterloo in Canada, who was not involved in the work, points out that Lukin and colleagues have done similar work on distributed quantum communication and the quantum internet. "The major difference is that for most of the original protocols, what people care about is trying to entangle different quantum memories in the quantum network so then they can do gates on those quantum memories," he says. "There's nothing about extra information from the environment. This one is different in that they have to get the information mapped from the starlight to their quantum memory."

Zhang notes several difficulties acknowledged by the researchers such as that vacancy centres are very narrowband, but says that now people know the system can work, they can show that it can beat classical systems in practice. Researchers in China led by Jian-Wei Pan at the University of Science and Technology of China, Hefei, also report they have achieved a similar result to the Harvard group, but their work has yet to be peer reviewed (arXiv: 2511.10988).

Materials

2D materials help spacecraft electronics resist radiation damage

Electronics made from certain atomically thin materials can survive harsh radiation environments up to 100 times longer than traditional silicon-based devices. This finding, which comes from researchers at Fudan University in Shanghai, China, could bring significant benefits for satellites and other spacecraft, which are prone to damage from intense cosmic radiation (*Nature* **650** 346).

Cosmic radiation consists of a mixture of heavy ions and cosmic rays, which are high-energy protons, electrons and atomic nuclei. The Earth's magnetic field protects us from 99.9% of this ionizing radiation, and our atmosphere significantly attenuates the rest. Space-based electronics, however, have no such protection, and this radiation can damage or even destroy them.

Adding radiation shielding to spacecraft mitigates these harmful effects, but the extra weight and power consumption increase the spacecraft's costs. "Implementing radiation tolerant electronic circuits is therefore an important challenge and if we can find materials that are intrinsically robust to this radiation, we could incorporate these directly into the design of onboard electronic circuits," says team leader Peng Zhou, a physicist in Fudan's College of Integrated Circuits and Micro-Nano Electronics.

Previous research had suggested that 2D materials might fit the bill, with transistors based on transition-metal dichalcogenides appearing particularly promising. Within this family of materials, 2D molybdenum disulphide (MoS_2) has proved especially robust to irradiation-induced defects. In their work, Zhou and colleagues set out to test the circuits under real space conditions. After growing monolayer 2D MoS_2 using chemical vapour deposition, they used this material to fabricate field-effect transistors. They then exposed these transistors to 10 Mrad of gamma-ray irradiation and looked for changes to their structure.

The measurements indicated that the 2D MoS_2 in the transistors was about 0.7 nm thick (typical for a monolayer structure) and showed no obvious signs of defects or damage. Subsequent Raman characterization on five sites within the MoS_2 film confirmed the devices' structural integrity. The researchers found that even after irradiation, the transistors' on-off ratios remained ultra-high, at about 10^8. They note that this is considerably better than a similarly-sized Si N-channel metal–oxide–semiconductor (NMOS) transistors fabricated through a CMOS process, for which the on-off ratio decreased by a factor of more than 4000 after the same 10 Mrad irradiation.

P Zhou

Lift-off
The robustness of molybdenum-disulphide structures against radiation damage has been tested on the Fudan No. 1 Lancang-Mekong Future satellite, which orbits Earth at an altitude of 517 km.

The team also found that the MoS_2 system consumes only about 49.9 mW per channel, making its power requirement at least five times lower than the NMOS one. The researchers tested their MoS_2 structures on a spacecraft orbiting at an altitude of 517 km, similar to the low-Earth orbit of many communication satellites. The tests showed that the bit-error rate in data transmitted from the structures remained below 10^{-8} even after nine months of operation. Based on test data, electronic devices made from these 2D materials could operate for 271 years in geosynchronous orbit – 100 times longer than conventional silicon electronics.

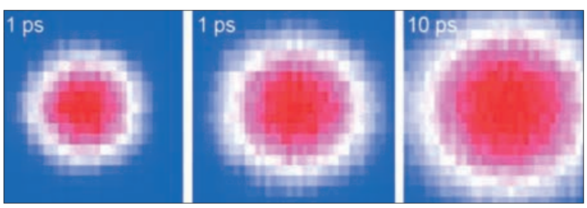
Isabelle Dumé

Metallic material breaks 100-year thermal conductivity record

A newly identified metallic material that conducts heat nearly three times better than copper could redefine thermal management in electronics. The material, known as theta-phase tantalum nitride (θ-TaN), has a thermal conductivity comparable to low-grade diamond. It was discovered by researchers at the University of California Los Angeles (UCLA), who say it breaks a record on heat transport in metals that had held for more than 100 years (*Science* 391 707).

Semiconductors and insulators mainly carry heat via vibrations, or phonons, in their crystalline lattices. Conventional metals, in contrast, mainly transport heat via the flow of electrons, which are strongly scattered by lattice vibrations.

Heat transport in θ-TaN combines aspects of both mechanisms. Although the material retains a metal-like electronic structure, study leader Yongjie Hu explains that its heat transport is phonon-dominated. Hu and his UCLA colleagues attribute this behaviour to the material's unusual crystal structure, which features tantalum atoms interspersed with nitrogen atoms in a hexagonal pattern. Such an arrangement suppresses both electron–phonon and phonon–phonon scattering, they say.



H-Lab/UCLA

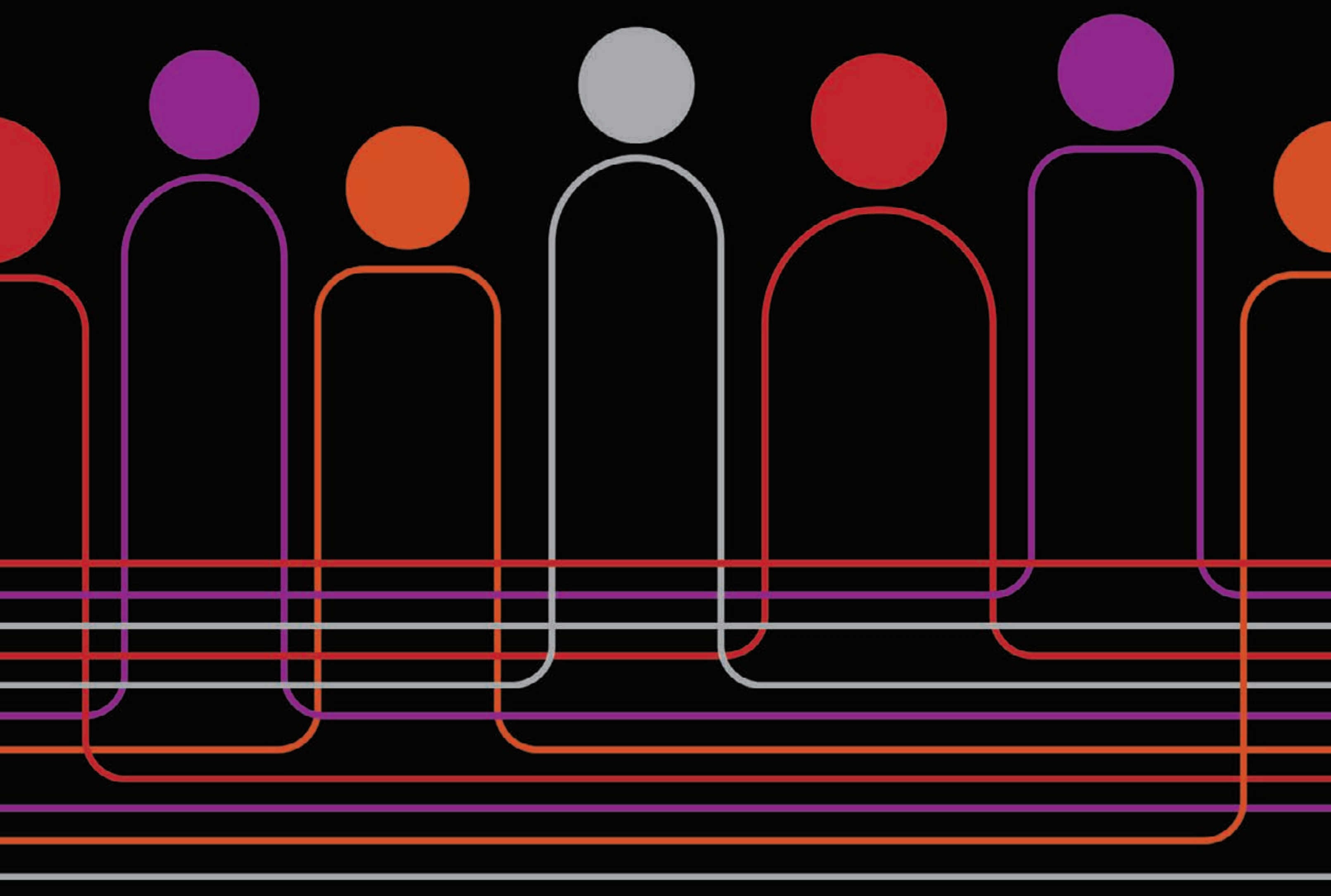
Super conductor
At room temperature, the thermal conductivity of the θ-TaN crystals is 1100 $Wm^{-1} K^{-1}$ – almost three times higher than copper.

Materials with high thermal conductivity are vital in electronic devices because they remove excess heat that would otherwise impair the devices' performance. Among metals, copper has long been the material of choice for thermal management thanks to its relative abundance and its thermal conductivity of around 400 $Wm^{-1} K^{-1}$, which is higher than any other pure metal apart from silver.

Hu and colleagues measured the thermal conductivity of the θ-TaN crystals at temperatures between 150 and 600 K. At room temperature, the thermal conductivity of the θ-TaN crystals was 1100 $Wm^{-1} K^{-1}$. "This is the highest value reported for any metallic materials to date," Hu says. The researchers also found that the thermal conductivity remained uniformly high across an entire crystal.

The UCLA team now plan to explore scalable ways of integrating θ-TaN into device-relevant platforms, including thin films and interfaces for microelectronics.

Isabelle Dumé



Opinion

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Quantum challenges

Funding cuts to particle and astronomy could inadvertently hamper quantum tech

I went to an unusual event last month. Now in its seventh year, Careers in Quantum is entirely organized by PhD students from the Centre for Doctoral Training (CDT) in quantum engineering at the University of Bristol. As well as giving them hands-on experience creating an event featuring businesses in the burgeoning quantum-tech sector, it also lets them build links with the very firms they might end up working for.

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With a careers fair attended by companies such as Phasecraft, Riverlane and Sparrow Quantum , the event is a win-win for students and businesses alike. There's now a whole ecosystem of quantum firms and it's clear you no longer need a PhD in quantum physics to break in. "Soft skills" such as communication, teamwork and a willingness to learn are just as vital.

But for the sector to truly thrive it needs a pipeline of talented physicists, which is why funding changes at UK Research and Innovation (UKRI), the umbrella organization for the UK's research councils, are so concerning. Although quantum tech is set to benefit from UKRI's "reprioritization" of its £38.6bn budget over the four years to 2030, particle physics and astronomy are facing cuts of at least 30%.

As well as making UK physics appear to be an unreliable partner on the international stage, with various projects in doubt, the cuts are not good PR for physics. After all, it's the prospect of discovering new particles at CERN or studying the Big Bang that attracts people into physics in the first place. I doubt many budding physicists study the subject because they hope one day to join a quantum start-up; but once they are hooked by physics, they very well might.

The heads of university physics departments in the UK have already published an open letter expressing their "deep concern" about funding changes at UKRI (see p3). Addressed to science minister Patrick Vallance, the letter says the cuts to particle physics and related areas are causing "reputational risk" and calls for "strategic clarity and stability" so UK physics can thrive.

It's a delicate balancing act for the heads, some of whose staff will benefit from the UKRI's changes, especially if money goes into quantum tech and AI. Physicists would do well to bear in mind a remark made at Careers in Quantum by Carrie Weidner, director of the quantum-engineering CDT, who stressed the importance of learning to fail. "If you're resilient and can think critically," she said, "you can do anything." That resilience is exactly what's needed right now.

Matin Durrani, editor-in-chief, *Physics World*

CERN needs a 'Plan B'

The fragmenting world order makes plans to build the Future Circular Collider questionable, warns **Michael Riordan**

Last November I visited the CERN particle-physics lab near Geneva to attend the 4th International Symposium on the History of Particle Physics, which focused on advances in particle physics during the 1980s and 1990s. As usual, it was a refreshing, intellectually invigorating visit. I'm always inspired by the great diversity of scientists at CERN – complemented this time by historians, philosophers and other scholars of science.

As noted by historian John Krige in his opening keynote address, "CERN is a European laboratory with a global footprint. Yet for all its success it now faces a turning point." During the period under examination at the symposium, CERN essentially achieved the "world laboratory" status that various leaders of particle physics had dreamt of for decades.

By building the Large Electron Positron (LEP) collider and then the Large Hadron Collider (LHC), the latter with contributions from Canada, China, India, Japan, Russia, the US and other non-European nations, CERN has attracted researchers from six continents. And as the Cold War ended in 1989–1991, two prescient CERN staff members developed the World Wide Web, helping knit this sprawling international scientific community together and enable extensive global collaboration.

The LHC was funded and built during a unique period of growing globalization and democratization that emerged in the wake of the Cold War's end. After the US terminated the Superconducting Super Collider in 1993, CERN was the only game in town if one wanted to pursue particle physics at the multi-TeV energy frontier. And many particle physicists wanted to be involved in the search for the Higgs boson, which by the mid-1990s looked as if it should show up at accessible LHC energies.

Having discovered this long-sought particle at the LHC in 2012, CERN is now contemplating an ambitious construction project, the Future Circular Collider (FCC). Over three times larger than the LHC, it would study this all-important, mass-generating boson in greater detail using an electron–positron collider dubbed FCC-ee, estimated to cost $18bn and start operations by 2050.

Later in the century, the FCC-hh, a proton–proton collider, would go in the same tunnel to see what, if anything, may lie at

CERN/Polar Media

Cost measures CERN is proposing the Future Circular Collider to study the Higgs boson in great detail, but can it afford the $18bn price tag?

much higher energies. That collider, the cost of which is currently educated guesswork, would not come online until the mid 2070s.

But the steadily worsening geopolitics of a fragmenting world order could make funding and building these colliders dicey affairs. After Russia's expulsion from CERN, little in the way of its contributions can be expected. Chinese physicists had hoped to build an equivalent collider, but those plans seem to have been put on the backburner for now.

And the "America First" political stance of the current US administration is hardly conducive to the multibillion-dollar contribution likely required from what is today the world's richest (albeit debt-laden) nation. The ongoing collapse of the rules-based world order was recently put into stark relief by the US invasion of Venezuela and abduction of its president Nicolás Maduro, followed by Donald Trump's menacing rhetoric over Greenland.

Recent events suggest how difficult it may become to fund gargantuan international scientific projects such as the FCC

While these shocking events have immediate significance for international relations, they also suggest how difficult it may become to fund gargantuan international scientific projects such as the FCC. Under such circumstances, it is very difficult to imagine non-European nations being able to contribute a hoped-for third of the FCC's total costs.

But the mounting European populist right-wing parties are no great friends of physics either, nor of international scientific endeavours. And Europeans face the not-insignificant costs of military rearmament in the face of Russian aggression and likely US withdrawal from Europe.

So the other two thirds of the FCC's many billions in costs cannot be taken for granted – especially not during the decades needed to construct its 91 km tunnel, 350 GeV electron–positron collider, the subsequent 100 TeV proton collider, and the massive detectors both machines require.

According to former CERN director-general Chris Llewellyn Smith in his symposium lecture, "The political history of the LHC", just under 12% of the material project costs of the LHC eventually came from non-member nations. It therefore warps the imagination to believe that a third of the much greater costs of the FCC can come from non-member nations in the current "Wild West" geopolitical climate.

But particle physics desperately needs a

Higgs factory. After the 1983 Z boson discovery at the CERN SPS Collider, it took just six years before we had not one but two Z factories – LEP and the Stanford Linear Collider – which proved very productive machines. It's now been more than 13 years since the Higgs boson discovery. Must we wait another 20 years?

Other options

CERN therefore needs a more modest, realistic, productive new scientific facility – a "Plan B" – to cope with the geopolitical uncertainties of an imperfect, unpredictable world. And I was encouraged to learn that several possible ideas are under consideration, according to outgoing CERN director-general Fabiola Gianotti in her symposium lecture, "CERN today and tomorrow".

Three of these ideas reflect the European Strategy for Particle Physics, which states that "an electron–positron Higgs factory is the highest-priority next CERN collider". Two linear electron–positron colliders would require just 11–34 km of tunnelling and could begin construction in the mid-2030s, but would involve a fair amount of technical risk and cost roughly €10bn.

The least costly and risky option, dubbed LEP3, involves installing superconducting radio-frequency cavities in the existing LHC tunnel once the high-luminosity proton run ends. Essentially an upgrade of the 200 GeV LEP2, this approach is based on well-understood technologies and would cost less than €5bn but can reach at most 240 GeV. The linear colliders could attain over twice that energy, enabling research on Higgs-boson decays into top quarks and the triple-Higgs self-interaction.

Other proposed projects involving the LHC tunnel can produce large numbers of Higgs bosons with relatively minor backgrounds, but they can hardly be called "Higgs factories". One of these, dubbed the LHeC, could only produce a few thousand Higgs bosons annually and would allow other important research on proton structure functions. Another idea is the proposed Gamma Factory, in which laser beams would be backscattered from LHC beams of partially stripped ions. If sufficient photon energies and intensity can be achieved, it will allow research on the $\gamma\gamma \rightarrow H$ interaction. These alternatives would cost at most a few billion euros.

As Krige stressed in his keynote address, CERN was meant to be more than a scientific laboratory at which European physicists could compete with their US and Soviet counterparts. As many of its founders intended, he said, it was "a cultural weapon against all forms of bigoted nationalism and anti-science populism that defied Enlightenment values of critical reasoning". The same logic holds true today.

In planning the next phase in CERN's estimable history, it is crucial to preserve this cultural vitality, while of course providing unparalleled opportunities to do world-class science – lacking which, the best scientists will turn elsewhere.

I therefore urge CERN planners to be daring but cognizant of financial and political reality in the fracturing world order. Don't for a nanosecond assume that the future will be a smooth extrapolation from the past. Be fairly certain that whatever new facility you decide to build, there is a solid financial pathway to achieving it in a reasonable time frame.

The future of CERN – and the bracing spirit of CERN – rests in your hands.

Michael Riordan is author of *The Hunting of the Quark* and lead author of *Tunnel Visions: the Rise and Fall of the Superconducting Super Collider*

Critical Point Lessons from the past


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Particle physics is using ever more interdisciplinary means to seek ever more exotic phenomena, **Robert P Crease** finds, but these ambitions might be threatened by the increasing isolation, fragmentation and polarization of the modern world

In his opening remarks to the 4th International Symposium on the History of Particle Physics, Chris Llewellyn Smith – who was a director-general of CERN in the 1990s – suggested participants should speak about "what's not written in the journals", including "mistakes, dead-ends and problems with getting funding". Doing so, he said, would "provide insight into the way science really progresses".

The symposium was not your usual science conference. Held last November at CERN, it took place inside the lab's 400-seat main auditorium, which has been the venue for many historic announcements, including the discovery of the Higgs boson. Its brown-beige walls are covered with lively designs by the Finnish artist Ilona Rista, suggesting to me the aftermath of a collision of high-energy bar codes.

The focus of the meeting was the development of particle physics in the 1980s and 1990s – a period that saw the construction and operation of various important accelerators and detectors. At CERN, these included the UA1 and UA2 experiments at the Super Proton Synchrotron, where the W and Z bosons were discovered. Later, there was the Large Electron-Positron Collider (LEP), which came online in 1989, and the Large Hadron Collider (LHC), approved five years later.

Delegates also heard about the opening of various accelerators in the US during those two decades, including two at the Stanford Linear Accelerator Center – the Positron-Electron Project in 1980 and the Stanford Linear Collider in 1989. Most famous of all was the start-up of the Tevatron at Fermilab in 1983. Over at Dubna in the former Soviet Union, meanwhile, scientists built the Nuclotron, a superconducting synchrotron, which opened in 1992.

Conference speakers covered unfinished machines of the era as well. The US cancelled two proton–proton facilities – ISABELLE in 1983 and the Superconducting Super Collider (SSC) a decade later. The Soviet Union, meanwhile, abandoned the multi-TeV proton–proton collider UNK a few years later, though news has recently emerged that Russia might revive the project.

Several speakers recounted the discovery of the W and Z particles at CERN in 1983 and the discovery of the top quark at Fermilab in 1995. Others addressed the strange fact that fewer neutrinos from the Sun had been detected than theory suggested. The "solar-neutrino problem", as it was known, was finally resolved by Takaaki Kajita's discovery of neutrino oscillation in 1998, for which he shared the 2015 Nobel Prize for Physics with Art McDonald.

The conference also addressed unsuccessful searches for proton decay, axions, magnetic monopoles, the Higgs boson, supersymmetry particles and other targets. Other speakers described projects with highly positive outcomes, such as the advent of particle cosmology, or what some have jokingly dubbed "the heavenly lab". The development of string theory, grand unified theories and perturbative quantum chromodynamics was tackled too.

In an exchange in the question-and-answer session after one talk, the Greek physicist Kostas Gavroglu referred to many of such quests as "failures". That remark

Joint effort It was in the 1990s that CERN fully became the focus of international collaboration in high-energy physics – a role that is now becoming somewhat uncertain.

As a result of the Superconducting Super Collider's controversial closure, the centre of gravity of high-energy physics shifted to Europe

prompted the Australian-born US theoretical physicist Helen Quinn to say she preferred the term "falling forward"; such failures, she said, were instances of "I tried this, and it didn't work so I tried that".

In relating his work on detecting gravitational waves, the US Nobel-prize-winning physicist Barry Barish said he felt his charge was not to celebrate the importance of his discoveries nor the ingenuity of the route he took. Instead, Barish explained, his job was to answer the much more informal question: "What made me do what?".

His point was illustrated by the US theorist Alan Guth, who described the very human and serendipitous path he took to working on cosmic inflation – the super-fast expansion of the universe just after the Big Bang. When he started, Guth said, "all the ingredients were already invented". But the startling idea of inflation hinged on accidental meetings, chance conversations, unexpected visits, a restricted word count for *Physical Review Letters*, competitions, insecurities and "spectacular realizations" coalescing.

Wider world

Another theme that arose in the conference was that science does not unfold inside its own bubble but can have extensive and immediate impacts on the world around it. Two speakers, for instance, recounted the invention of the World Wide Web at CERN in the late 1980s. It's fair to say that no other discovery by a single individual – Tim Berners-Lee – has so radically and quickly transformed the world.

The growing role of international politics in promoting and protecting projects was mentioned too, with various speakers explaining how high-level political negotiations enabled physicists to work at institutions and experiments in other nations. The Polish physicist Agnieszka Zalewska, for example, described her country's path to membership in CERN, while Russian-born US physicist Vladimir Shiltsev spoke about the "diaspora" of Russian particle physicists after the fall of the Soviet Union in 1991.

Sometimes politics created destructive interference. The US physicist, historian and author Michael Riordan described how the US's determination to "go it alone" to outcompete Europe in high-energy physics was a major factor in bringing about the opposite: the termination of the SSC in 1993. As a result of that project's controversial closure, the centre of gravity of high-energy physics shifted to Europe.

Indeed, contemporary politics occasionally hit the conference itself in incongruous and ironic ways. Two US physicists, for example, were denied permission to attend because budgets had been cut and travel restrictions increased. In the end, one took personal time off and paid his own way, leaving his affiliation off the programme.

Before the conference, some people complained that conference organizers hadn't paid enough attention to physicists who'd worked in the Soviet Union but were from occupied republics. Several speakers addressed this shortcoming by mentioning people like Gersh Budker (1918–1977). A Ukrainian-born physicist who worked and died in the Soviet Union, Budker was nominated for a Nobel Prize (1957) and even has had a street named after him at CERN. Unmentioned, though, was that Budker was Jewish and that his father was killed by Ukrainian nationalists in a pogrom.

On the final day of the conference, which just happened to be World Science Day for Peace and Development, CERN mounted a public screening of the 2025 documentary film *The Peace Particle*. Directed by Alex Kiehl, much of it was about CERN's internationalism, with a poster for the film describing the lab as "Mankind's biggest experiment…science for peace in a divided world".

But in the Q&A afterwards some audience members criticized CERN for allegedly whitewashing Russia for its invasion of the Ukraine and Israel for genocide. Those onstage defended CERN on the grounds of its desire to promote internationalism.

The critical point

The keynote speaker of the conference was John Krige, a science historian from Georgia Tech who has worked on a three-volume history of CERN. Those who launched the lab, Krige reminded the audience, had radical "scientific, political and cultural aspirations" for the institution. Their dream was that CERN wouldn't just revive European science and promote regional collaborative effects after the Second World War, but also potentially improve the global world order too.

Krige went on to quote one CERN founder, who'd said that international science facilities such as CERN would be "one of the best ways of saving Western civilization". Recent events, however, have shown just how fragile those ambitions are. Alluding to CERN's Future Circular Collider and other possible projects, Llewellyn Smith ended his closing remarks with a warning.

"The perennial hope that the next big high-energy project will be genuinely global," he said, "seems to be receding over the horizon due to the polarization of world politics".

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Transactions Nuclear transport

Driving nuclear-powered cars has thankfully remained the stuff of dreams, but **Honor Powrie** wonders where "atomic transport" could take us next


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Going boldly Nuclear propulsion could be the perfect solution for deep-space missions.

In 1942 physicists in Chicago, led by Enrico Fermi, famously produced the world's first self-sustaining nuclear chain reaction. But it was to be another nine years before electricity was generated from fission for the first time. That landmark event occurred in 1951 when the Experimental Breeder Reactor-I in southern Idaho powered a string of four 200-watt light bulbs.

Our ability to harness nuclear power has been under constant development since then. In fact, according to the Nuclear Energy Association, a record 2667 terawatt-hours of electricity was generated by nuclear reactors around the world in 2024 – up 2.5% on the year before. But what, I wonder, is the potential of nuclear-powered transport?

A "nuclear engine" has many advantages, notably providing a vehicle with an almost unlimited supply of onboard power, with no need for regular refuelling. That's particularly attractive for large ships and submarines, where fuel stops at sea are few and far between. It's even better for space craft, which cannot refuel at all.

The downside is that a vehicle needs to be fairly large to carry even a small nuclear fission reactor – plus all the heavy shielding to protect passengers onboard. Stringent safety requirements also have to be met. If the vehicle were to crash or explode, the shield around the reactor needs to stay fully intact.

Ships and planes

Perhaps the best known transport application of nuclear power is at sea, where it's used for warships, submarines and supercarriers. The world's first nuclear-powered ship was the US Navy submarine *Nautilus*, which was launched in 1954. As the first vessel to have a nuclear reactor for propulsion, it revolutionized naval capabilities.

Compared to oil or coal-fired ships, nuclear-powered vessels can travel far greater distances. All the fuel is in the reactor, which means there is no need for additional fuel be carried onboard – or for exhaust chimneys or air intakes. Even better, the fuel is relatively cheap. But operating and infrastructure costs are steep, which is why almost all nuclear-powered marine vessels belong to the military.

There have, however, been numerous attempts to develop other forms of nuclear-powered transport. While a nuclear-powered aircraft might seem unlikely, the idea of flying non-stop to the other side of the world, without giving off any greenhouse-gas emissions, is appealing. Incredible as it might seem, airborne nuclear reactors were actually trialled in the mid-1950s.

That was when the United States Air Force converted a B-36 bomber to carry an operational air-cooled reactor, weighing around 18 tons. The aircraft was not actually nuclear powered but it was operated in this configuration to assess the feasibility of flying a nuclear reactor. The aircraft made a total of 47 flights between July 1955 and March 1957.

In 1955, the Soviet Union also ran a project to adapt a Tupolev Tu-95 "Bear" aircraft for nuclear power. However, because of the radiation hazard to the crew and the difficulties in providing adequate shielding, the project was soon abandoned. Neither the American or the Soviet atomic-powered aircraft ever flew and – because the technology was inherently dangerous – it was never considered for commercial aviation.

Cars and trains

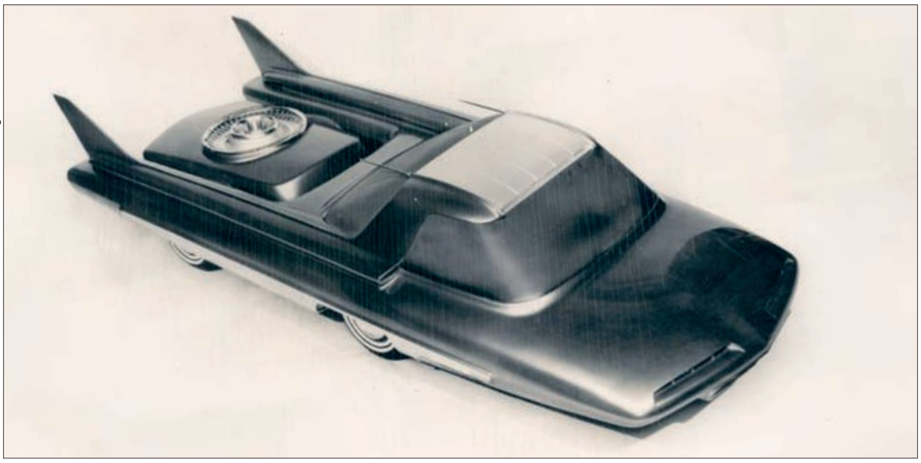
The same fate befell nuclear-powered trains. In 1954 the US nuclear physicist Lyle Borst, then at the University of Utah, proposed a 360-tonne locomotive carrying a uranium-235 fuelled nuclear reactor. Several other countries, including Germany, Russia and the UK, also had schemes for nuclear locos. But public concerns about safety could not be overcome and nuclear trains were never built. The $1.2m price tag of Borst's train didn't help either.

In the late 1950s, meanwhile, there were at least four theoretical nuclear-powered "concept cars": the Ford Nucleon, the Studebaker Packard Astral, the Simca Fulgur and the Arbel Symétric. Based on the assumption that nuclear reactors would get much smaller over time, it was felt that such a car would need relatively light radiation shielding. I certainly wouldn't have wanted to take one of those for a spin; in the end none got beyond concept stage.

But perhaps the real success story of nuclear propulsion has been in space. Between 1967 and 1988, the Soviet Union pioneered the use of fission reactors for powering surveillance satellites, with over 30 nuclear-powered satellites being launched during that period. And since the early 1960s, radioisotopes have been a key source of energy in space.

Driven by the desire for faster, more capable and longer duration space missions to the Moon, Mars and beyond, China, Russia and the US are now investing significantly in the next generation of nuclear reactor technology for space propulsion, where solar or radioisotope power will be inadequate. Several options are on the table.

One is nuclear thermal propulsion, whereby energy from a fission reactor heats a propellant fuel. Another is nuclear electric propulsion, in which the fission energy



Nuclear nightmare Ford's Nucleon car thankfully never got past the concept stage.

ionizes a gas that gets propelled out the back of the spacecraft. Both involve using tiny nuclear reactors of the kind used in submarines, except they're cooled by gas, not water. Key programmes are aiming for in-space demonstrations in the next 5–10 years.

Where next?

Many of the first ideas for nuclear-powered transport were dreamed up little more than a decade after the first self-sustaining chain reaction. The appeal was clear: compared to other fuels, nuclear power has a high energy density and lasts much longer. It also has zero carbon emissions. Nuclear power must have seemed a panacea for all our energy needs – using it for cars and planes must have seen an obvious next step.

However, there are major safety issues to address when nuclear sources are mobilized, from protecting passengers and crew, to ensuring appropriate safeguards should anything go wrong. And today we understand all too well the legacy of nuclear

Nuclear power must have seemed a panacea for all our energy needs

systems, from the safe disposal of spent fuel to the decommissioning of nuclear infrastructure and equipment.

Here on Earth, I think we've struck the right balance when it comes to using nuclear power, confining it to sea-faring vessels under the watchful eye of the military. But as human-crewed, deep-space exploration beckons, a whole new set of issues will arise. There will, of course, be lots of technical and engineering challenges.

How, for example, will we maintain, repair and decommission nuclear-powered space craft? How will we avoid endangering crews or polluting the environment especially when craft take off? Who should set appropriate legislation – and how we do we police those rules? When it comes to space, nuclear will help us "to boldly go"; but it will also require bold regulation.

Honor Powrie is an engineer who is now senior director for data science and analytics at GE in Southampton, UK. She is writing here in a personal capacity

Reviews

Friction stories rub along nicely

Mike Follows reviews *Friction: a Biography* by Jennifer R Vail

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Here, there and everywhere
Friction has an impact throughout our lives, whether it's melting a layer of snow under our skis, helping blood flow through arteries, letting us play a violin, or writing with a pencil.

Friction: a Biography
Jennifer R Vail
2026 Harvard University Press
248pp £23.95hb

People who teach physics often remove friction from calculations to make life easier for students. While that might speed up someone's homework, it does mean that this all-important force tends to fade into the background, despite it being crucial for our daily lives. Here to bring friction centre stage is Jennifer Vail, a "tribologist" – or studier of friction – at US firm TA Instruments.

Friction: a Biography is an engaging and wide-ranging book illustrating its many manifestations in the natural world, showing how this force can be harnessed to solve practical engineering problems. Vail, who wrote the book after giving a hugely popular TED talk on friction, does a great job of connecting abstract physical ideas with familiar human experience.

I like, for example, her description of what happens when two surfaces slide over each other but the friction between them isn't constant. As she explains, this "stick-slip" motion isn't great if you're trying to inject a drug into someone with a syringe. But it can be exploited to beautiful effect by violinists, creating "downright lovely" sounds (though apparently not when she's practising on her own viola).

One of the book's strengths is its historical context. Famous figures like Leonardo da Vinci are introduced alongside the development of their ideas, lending a human dimension to the science. The author does a great job of explaining how tribology, which comes from the Greek for "to rub", has been shaped by careful experimentation and the application of rigorous scientific thinking to industrial problems.

After a trip to Switzerland, for example, the Australian-born physicist Frank Bowden showed we can ski because frictional heating causes a thin layer of snow to melt beneath our skis, providing liquid lubrication. This overturned an earlier explanation associated with Osborne Reynolds (best known for the eponymous number marking the transition from laminar to turbulent flow) who'd thought that snow melts due to pressure.

Then there is the 19th-century researcher Robert Thurston, whose pendulum experiments on friction in bearings, described here in detail, guided the design of more efficient lubricated systems. As Vail explains, understanding friction is vital in the design of engines, where even small modifications – such as texturing surfaces, adding coatings, or putting nanoparticles into lubricants – can make them much more efficient and extend their useful life.

Historical anecdotes are woven throughout the book. The story of why graphite in pencils came to be called "lead" is particularly memorable. It turns out that the Romans used lead to write, so the name stuck – even after graphite became more popular because it allowed darker writing. There are also lots of excursions into the natural world: did you know that beetles have a protein in their leg joints that acts as a solid lubricant?

Smooth operator

Vail's discussion of lubrication is clear and well-integrated with practical examples. Particularly insightful is the explanation of how hydrodynamic lubrication occurs in biological systems, such as human cartilage, where a thin fluid layer separates cartilage surfaces in joints, reducing friction and wear. As Vail makes clear, tribology is vital in physiology, for example in how contact lenses work when we blink our eyes or how food feels in our mouth when we chew.

The book also examines fluid dynamics and drag, distinguishing between viscosity as a material property and drag as a force. Vail's discussion of plaque on the walls of our arteries is particularly compelling. If there's not enough drag to shear off the plaque it can cause blockages and, potentially, a heart attack – showing how friction plays a role in our health.

Environmental considerations are

addressed too. The author discusses, for example, the impact of polytetrafluoroethalyene (PTFE), which she calls "the most controversial solid lubricant ever". Also known as Teflon, it is widely used in frying pans, but is synthesized using some pretty nasty carcinogenic "forever" chemicals that don't break down in the environment. PTFE also has a shady past, being first used in the Manhattan atomic-bomb project to coat valves when separating isotopes of uranium.

On a more positive note, Vail shows how an understanding of friction can improve energy efficiency, reduce greenhouse-gas emissions, and mitigate global warming. The book extends further still, encompassing atmospheric, oceanic and planetary processes, as well as astronomy and cosmology. Friction is a universal physical principle, extending well beyond conventional engineering applications and broadening the scope of the book.

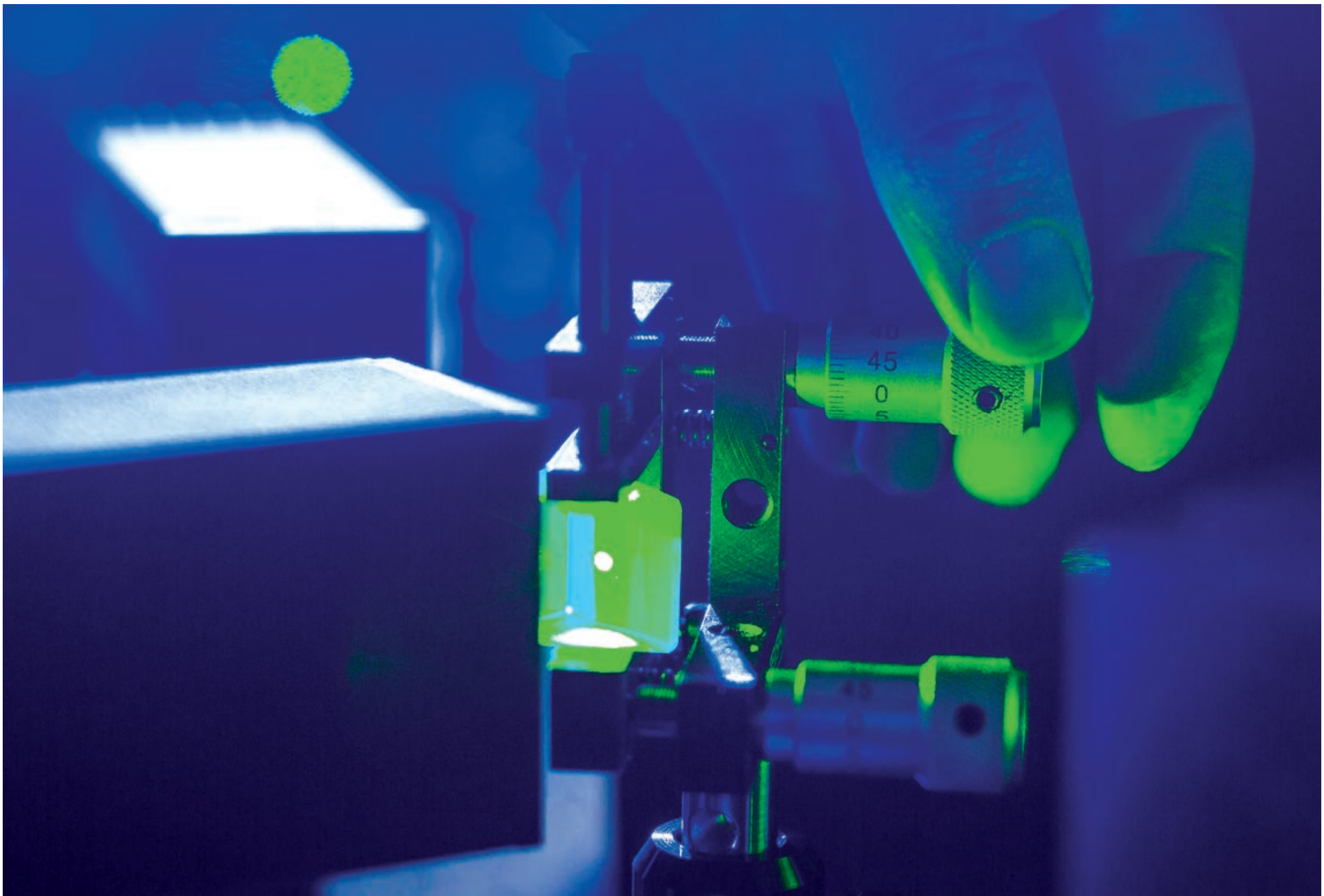
Friction can improve energy efficiency, reduce greenhouse-gas emissions, and mitigate global warming

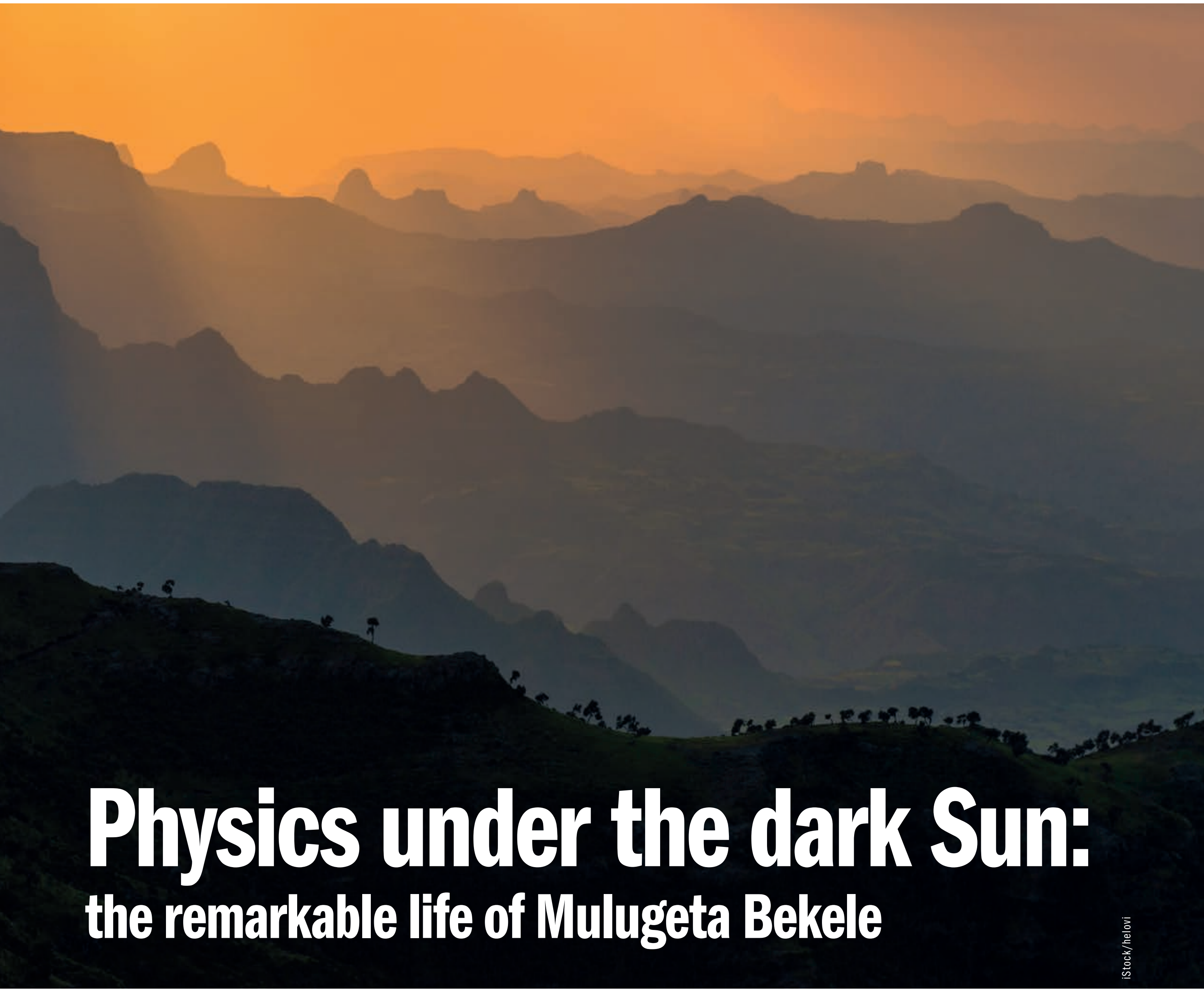
However, Vail's intended audience is not always clear. Some sections read like a primer for tribologists, while others are highly speculative, such as the idea that life originated on Earth because oxidized molybdenum was delivered from Mars aboard Martian meteorites. There are also occasional errors and ambiguities, such as her discussion of the subtleties of the Earth's tides.

Statements such as electric vehicles "consuming 106% energy" could have been more clearly explained, while her market estimate for anti-friction coatings of just over $1.5m by 2028 is almost certainly too low by three orders of magnitude. While these issues do not undermine the book's scientific substance, they may distract careful readers, and the rapid movement between topics occasionally disrupts the narrative flow.

Overall, though, Vail does a good job of balancing technical exposition with anecdote and gentle humour. Friction might seem an unpromising subject for a book, but non-expert readers will find much to surprise and engage them. Despite its flaws, I would recommend it as an illuminating, if imperfect, celebration of friction and its central role in science and engineering.

Mike Follows teaches physics at King Edward's School, Birmingham, UK, and is the foundation leader in education for physics for the 14 schools in the trust, e-mail mikefollows@physics.org





Physics under the dark Sun: the remarkable life of Mulugeta Bekele

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Mulugeta Bekele is almost single-handedly responsible for having kept Ethiopian physics going in the 1970s and 1980s despite being imprisoned and tortured by the Ethiopian military. **Robert P Crease** meets an unsung hero of science

Mulugeta Bekele paid a heavy price for remaining in Ethiopia in the 1970s and 1980s. While many other academics had fled their homeland to avoid being targeted by its military rulers, Mulugeta did not. He stayed to teach physics, almost single-handedly keeping it alive in the country. But Mulugeta was arrested and brutally tortured by members of the Derg, Ethiopia's ruling military junta. "I still have scars," he says when we meet at his tiny, second-floor office at Addis Ababa University (AAU) in January 2026.

Gentle and softly-spoken, Mulugeta, 79, is formally retired but still active as a research physicist. In 2012 his efforts led to him being awarded the Sakharov prize by the American Physical Society (APS) "for his tireless efforts in defence of human rights and freedom of expression and education anywhere in the world, and for inspiring students, colleagues and others to do the same".

Mulugeta was born in 1947 near Asela, a small town south of Ethiopia's capital Addis Ababa. The district had only a single secondary school that depended on volunteer teachers from other countries. One was a US Peace Corps volunteer named Ronald Lee, who taught history, maths and science for two years. Mulugeta recalls Lee as a dramatic and inventive teacher, who would climb trees in physics classes to demonstrate the actions of pulleys and hold special after-school calculus classes

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Robert P Crease

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Ruthless ruler Mengistu Haile Mariam (left) was a leader of Derg military junta and communist dictator in Ethiopia between 1977 and 1991. He is shown alongside two other senior members of the Derg: Tafari Benti (middle) and Atnafu Abate (right).

A challenging life Mulugeta Bekele at Addis Ababa University, Ethiopia, in January 2026 while speaking to *Physics World*.

for advanced students.

Mulugeta and other Asela students were entranced. So when he entered AAU – then called Haile Selassie 1 University – in 1965, Mulugeta declared he wanted to study both mathematics and physics. Impossible, he was informed; he could do one or the other but not both. “I told myself that if I choose mathematics I will miss physics,” Mulugeta says. “But if I do physics, I will be continually engaged with mathematics.” Physics it was.

At the end of his third year, Mulugeta’s studies appeared in doubt. The university’s only physics teacher was an American named Ennis Pilcher, who was about to return to Union College in Schenectady, New York, after spending a year in Addis on a fellowship from the Fulbright Program. Pilcher, though, managed to convince Union to support Mulugeta so he could travel to the US and study physics there for his final year.

As I talk to Mulugeta, he pulls a dusty book off his shelf. “This was given to me by Pilcher,” he says, pointing to Walter Meyerhof’s classic undergraduate textbook *Elements of Nuclear Physics*. Mulugeta turns to the inside of the front cover and proudly shows me the inscription: “Mulugeta Bekele, Union College. Schenectady, 1969–1970”.

When Mulugeta returned to AAU in the summer of 1970, he was awarded a BSc in physics. He then received a grant from the US Agency for International Development (USAID) to attend the University of Maryland for a master’s degree. After two more years in the US, Mulugeta returned to Addis Ababa in 1973. As an accomplished researcher and teacher, he was made department chair and began to expand the physics programme at the university.

In the firing line

It was a time when political turmoil was upending Ethiopia, as well as the lives of Mulugeta and many other academics. For centuries the country had been ruled by a dynasty whose present emperor was Haile Selassie. Having come to the throne in 1930, he had tried to reform Ethiopia by bringing it into the League of Nations, drawing up a constitution, and taking measures to abolish slavery.

When fascist Italy invaded Ethiopia in May 1935, Selassie left, spending six years in exile in the UK during the Italian occupation of the country. He returned as emperor in 1941 after British and Ethiopian forces recaptured Addis Ababa. But famine, unemployment and corruption, as well as a brief unsuccessful coup attempt, undermined his rule and made him unexpectedly vulnerable.

While in Maryland, Mulugeta and other Ethiopian students in the US started supporting the Ethiopian People’s Revolutionary Party (EPRP) – a pro-democracy group that sought to build popular momentum against the monarchy. In February 1974 Selassie was deposed by the Derg – a repressive military junta named after the word for “committee” in Amharic, the most widely spoken language in Ethiopia. Selassie was assassinated the following year.

Led by an army officer named Mengistu Haile Mariam, the Derg’s radical totalitarianism was in sharp contrast to the student-led EPRP’s efforts and its agenda included seizing property from landowners. Mulugeta’s family lost all its land, and his father was killed fighting the Derg. “Land ownership was still inequitable,” Mulugeta remarks ruefully, “only the landlords changed.”

In September 1976 the EPRP tried, unsuccessfully, to assassinate Mengistu. The following February, on becoming chairman of Derg – and therefore head of state – Mengistu began ruthlessly to crush any opposition, particularly the EPRP, in what he himself called the “Red terror” campaign of political suppression. About half a million people in Ethiopia were killed.

“It was a police state,” recalls Solomon Bililign, Mulugeta’s then graduate assistant, now a professor of atomic and molecular physics at North Carolina Agricultural and Technical State University. “The police didn't need any reason to arrest you. They would arrest people openly in the streets, break into homes, and left people dead in roads and parks. Many were tortured; others simply disappeared."

Captured and tortured

Mulugeta himself was a target. In the summer of 1977, a policeman showed up at his office with an informant. Mulugeta was arrested and imprisoned for his role in helping to organize anti-Derg activities, as was Bililign. Mulugeta still recalls exactly how long he was jailed for: "Eight months and 20 days".

After his release, Mulugeta knew it would be unsafe to stay in Addis and lived in hiding for several months. So he devised a plan to travel 500 km north to a hold-out region not controlled by the Derg. However, while using a fake ID to pass through checkpoints to reach a compatriot, he was betrayed again, captured, and taken back to Addis.

En route to Addis, he managed to steal back the fake ID that he'd been using from the pocket of the policeman travelling with him. He then tore it up to shield the identity of his compatriot, and tossed the pieces into a toilet. But the policeman noticed and retrieved the pieces. Mulugeta was then savagely tortured using a method that the Derg meted out on thousands of other prisoners. His arms and legs were tied around a pole, and he was hung in the foetal position between two chairs, upside down. His feet were then beaten until he could no longer walk.

Mulugeta was sent to Maekelawi, an infamous jail in Addis, in which up to 70 prisoners could be jammed in rooms each barely four metres long and four metres wide. Inmates were tortured without warning, could not have visitors, never had trials, were denied books and paper, and at night heard screams from periodic executions. Mulugeta helped those who were beaten by tending to their wounds.

"People who knew him in prison told me that his mental strength helped all of them endure," remembers Mesfin Tsige, an undergraduate student of Mulugeta at the time, who is now a polymer physicist at the University of Akron in Ohio. Despite the awful conditions, Mulugeta managed to continue working on physics by surreptitiously taking paper from the foil linings of cigarette packets to compose problems.

Another prisoner was Nebiy Mekonnen, a chemistry student of Mulugeta. Later a gifted artist, translator and newspaper editor, Mekonnen began translating the US writer Margaret Mitchell's classic 1936 book *Gone with the Wind* into Amharic. It was the one book that the Maekelawi prisoners had in their hands, having retrieved it from the possessions of someone who had been executed.

Surreptitiously writing his translation onto the foil linings of cigarette packets, Mekonnen would read passages to fellow prisoners in the evening for what passed for entertainment. Mekonnen's translation of Mitchell's almost 1000-page book was recorded onto 3000 of the linings, which were then smuggled out of the prison stuffed in tobacco pouches and published years later.

Gone with the Wind might seem a strange choice to translate, but as Mulugeta reminds me: "It was the only book we had at the time". More smuggled books did eventually arrive at the prison, but *Gone with the Wind*, which describes life in a war-torn country, has several passages that resonated with prisoners. One was: "In the end what will happen will be what has happened whenever a civilization breaks up. The people with brains and courage come through and the ones who haven't are winnowed out."

Happier times Mulugeta Bekele (front centre in the white top), Solomon Bililign (next to him in the purple shirt) and Nebiy Mekonnen (back row, with the hat) pictured with their family and friends. All three were incarcerated together at the notorious Maekelawi prison.

Kerchele prison school was not short of teachers, as the prisoners included a wide range of professionals

Release and recapture

In 1982, Mulugeta was moved to Kerchele, another prison. There, as at Maekelawi, inmates were forced to listen to Mengistu's pompous speeches on radio and TV. During one Mengistu pontificated that he would turn prisons into places of education. A clever inmate, knowing that the prison wardens were also cowering in terror, proposed that Kerchele establish a school with the prisoners as teachers.

The wardens found this a great idea, not least because it let them show off their loyalty to Mengistu. The Kerchele prisoners were promptly put to work erecting a schoolhouse of half a dozen rooms out of asbestos slabs. Unlike schools in the rest of Ethiopia, the Kerchele prison school was not short of teachers, as the prisoners included a wide range of professionals, such as architects, scientists and engineers.

Students included prison guards and their families, along with numerous inmates who had been jailed for non-political reasons. Mulugeta and Bililign taught physics. "It was therapy for us," Bililign says – and the school was soon known as one of the best in Ethiopia.

Solomon Bililign

Honoured figure Mulugeta Bekele with his wife Malefia at the March 2012 meeting of the American Physical Society in Boston, where he was awarded the Sakharov medal for his "tireless efforts in defence of human rights and freedom of expression".

When I ask Mulugeta how he maintained his interest in physics in jail, despite being locked up for so many years, he becomes animated. "In those days, prisons were full of ideas," he smiles. "We were university students, university teachers. We had a cause. It was exciting. Intellectually, we flourished."

In the summer of 1985 Mulugeta was released. Many colleagues were not. "They were given release papers and as they left the building, one by one, they were strangled. I had a tenth-grade student who was one of the best; he didn't make it. There were plenty of stories like this." Mulugeta pauses. "Somehow we survived. But not them."

Mulugeta returned to the university, now renamed from Haile Selassie University to Addis Ababa University, and started teaching physics full time. As the Derg was in full control no opposition was possible except in outer regions of Ethiopia. In summer 1991, after Mulugeta had taught physics for another six years, political turmoil erupted yet again.

Mengistu was overthrown that May by a political coalition representing pro-democracy groups from five of Ethiopia's ethnic regions, the Ethiopian People's Revolutionary Democratic Front (EPRDF). But ethnic tensions rose and human rights violations continued. "Even though the Derg was overthrown," Mulugeta recalls, "we knew we were entering another dark age."

In the same year Mulugeta was put in touch with a Swedish programme seeking to build networks of scientists across countries in the southern hemisphere. Mulugeta knew a physicist from Bangalore, India, who had visited Addis twice as an examiner for his master's programme and arranged to work with him for his PhD.

That July, Mulugeta married Malefia, who worked in the university's registrar office, and the two left for Bangalore. As a wedding present, his student Mekonnen painted a picture of two hands coming together, each with a ring on a finger, against a black Sun in the background. "Two rings, in the time of a dark sun" Mekonnen's caption read, "Happy marriage!" Mulugeta still has the painting.

In Bangalore Mulugeta was finally able to combine his two loves, physics and maths

Mulugeta thrived in Bangalore. Here, he was finally able to combine his two loves, physics and maths, studying statistical physics and stochastic processes and applying them to issues in non-equilibrium thermodynamics. He has worked in that field ever since. He received his PhD in 1998 from the Indian Institute of Science in Bangalore and returned to Addis once more to teach.

Shortly after Mulugeta's return from Bangalore to Ethiopia in August 1998, some of his former students formed the Ethiopian Physical Society, electing him as its first president. Other students of his who had taken positions in the US created the Ethiopian Physical Society of North America (EPSNA), formally established in 2008. Bililign organized and convened its first meeting.

In 2007, Philip Taylor, a soft-condensed-matter physicist from Case Western Reserve University in the US, who had been Tsige's PhD supervisor, heard the story of Mulugeta's imprisonment. Astonished, he spearheaded the successful 2012 application for Mulugeta to receive the APS's Sakharov prize, which is given every two years to physicists who have displayed "outstanding leadership and achievements of scientists in upholding human rights".

Unsure that he would receive travel funds to attend a special award ceremony at that year's APS March meeting in Boston, the EPSNA raised money for Mulugeta and his wife to attend. Jetlagged, worn out by the cold, and somewhat overwhelmed by the attention, Mulugeta could not be found as the ceremony began. EPSNA members tracked him down to his hotel room, where he was dressing in traditional Ethiopian clothes for the occasion – all white from head to toe, including shoes.

Under the dark Sun

In recent years, Mulugeta has continued to teach and collaborate with students and former students, publishing in a wide range of journals, as well as helping out with the Ethiopian Physical Society. But while I was in Ethiopia to talk to Mulugeta at the start of 2026, the Trump administration curtailed immigrant visas from Ethiopia and almost half of all nations in Africa supposedly in an attempt to "protect the security of the United States". A few months before, it had imposed a $100,000 fee on work visas, all but preventing US universities from hiring non-US citizens. It killed the USAID programme that had once sent Mulugeta to the US for his master's degree.

The Trump administration has also withdrawn the US from international scientific organizations, conventions and panels, and has gutted the most important US scientific agencies. These and other measures are destroying the networks of international physics collaborations of the kind that Mulugeta both promoted and benefited from – networks that nurture education, careers and knowledge.

"We are not yet in good hands," Mulugeta warns me as I start to leave. "We are," he says, "still under the dark Sun."

Paving the way for sustainable structures

Concrete shapes the world around us and is a staple for our infrastructure – but it is also one of the biggest carbon emitters. **Benjamin Skuse** asks if concrete's climate impact can be tamed by physics, and what role AI can play

Benjamin Skuse is a freelance science journalist based in the UK

Grey, ugly, dull. Concrete is not the most exciting material in the world. That is, until you start to think about its impact on our lives. Concrete is the second most consumed material on the planet after water. Humanity uses about 30 billion tonnes of the stuff every year, the equivalent of building an entire new New York City every month. Put another way, there is so much concrete in the world and so much being made that by the 2040s it will outweigh all living matter.

As the son of a builder, I have made a few concrete mixes over the years myself, usually following my father's tried and trusted recipe. Take one part cement (fine mineral powder), two parts sand, and four parts aggregate (crushed stone), then mix and add enough water until it all goes gloopy.

The ubiquity and low cost of these simple ingredients are just two of the reasons for concrete's global reach. In liquid form, it can be moulded into almost any shape, and once set, it is as hard and durable as stone. What's more, it doesn't burn, rot or get eaten by animals.

These factors make concrete the ideal material for everything from vast imposing dams to sleek kitchen floors. However, its gargantuan presence across society comes at an equally epic environmental cost. If concrete were a country, it would rank third behind only the US and China as a greenhouse gas emitter.

Though raw material processing and transport of concrete are part of the problem, concrete's biggest environmental impact comes from the heat and chemical processes involved in producing cement. Ordinary cement clinker (the raw form of cement before it is ground to a powder) is the product of heating limestone up to 1450 °C until it breaks apart into lime and carbon dioxide (CO_2). This heating requires lots of energy and the chemical process releases huge amounts of the greenhouse gas CO_2 – meaning that cement makes up around 90% of the carbon footprint of an average concrete mix.

In the UK and some other parts of the world, this climate impact is well recognized, with the industry having made significant efforts to decarbonize over the last few decades. "Since 1990, the UK concrete industry has decreased its direct and indirect environmental impacts by over 53% through various technology levers," says Elaine Toogood – an architect and senior director at the Mineral Products Association's Concrete Centre, the UK's technical hub for all things concrete.

This reduction has been achieved through actions such as fuel switching, decarbonizing electricity and transport networks, and carbon capture technology. "For example, over 50% of all the heat that's needed to make cement is now supplied by waste-derived fuels," Toogood adds.

Yet the sheer scale of the global concrete industry means that much more needs to be done to fully mitigate concrete's carbon impact. Can physics, and more specifically AI, lend a hand?

Low-carbon replacements

Replacing cement – concrete's least green ingredient – with low-carbon alternatives seems like a good place to start. Two well-proven options have been available for decades.

Fly ash – the by-product of burning coal at power plants – can replace about 30% of cement in concrete mixes. It has been used in the construction of many prominent

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structures including the Channel Tunnel, which opened in 1994. Blast furnace slag – the by-product of iron and steel production – is another capable replacement, and can make up to 70% of cement content. Slag was used in 2009 to substitute half of the regular cement in the precast concrete units that now make up the sea defences on Blackpool beach.

Yet although these waste materials are currently extensively used as cement or concrete additions in the UK and elsewhere, they rely on very polluting sources (coal-fired power plants and blast furnaces) that are gradually being phased out globally to meet climate targets. As a result, fly ash and blast furnace slag are not long-term solutions. New low-carbon materials are needed, which is where physics can play a decisive role.

Based in Debre Tabor University in Ethiopia, Gashaw Abebaw Adanu is an expert in innovative construction materials. In 2021 he and colleagues investigated the potential of partially replacing (0%, 5%, 10%, 15% and 20%) standard cement with ash from burning lowland Ethiopian bamboo leaf, a common local construction waste material (*Adv. Civ. Eng* 10.1155/2021/6468444). The findings were encouraging. Though the concrete took longer to set with increased bamboo leaf ash content, the material's strength, water absorption and sulphate attack (concrete breakdown caused by sulphate ions reacting with the hardened cement paste) improved for 5–10% bamboo leaf ash mixes. The results suggest that up to 10% of cement could be swapped for this local low-carbon alternative.

Steel, copper – or hair?

More recently, Adanu has turned his focus to concrete fibre reinforcement. Adding small amounts of steel, copper or polyethene fibres is known to increase concrete's ductility and crack resistance by up to 200% and

> Replacing cement – concrete's least green ingredient – with low-carbon alternatives seems like a good place to start

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Shapely material Concrete is ubiquitous in modern buildings, from generic office blocks (top left) to some of the world's most creative architecture, such as (top right) the Auditorio de Tenerife in Santa Cruz (designed by Santiago Calatrava) and (bottom left) the Metropolitan Cathedral Nossa Senhora Aparecida in Brasilia (designed by Oscar Niemeyer). But it can be found in much older buildings as well. The largest unreinforced concrete dome in the world (bottom right) is on the Pantheon in Rome, built in 126 CE. This structure uses volcanic dust as its cement.

90%, respectively. The tiny fibres act like micro-stitches throughout the entire mix, transforming concrete from a brittle material into a tough, energy-absorbing composite.

Fibre reinforcement also leads to major cost savings and a reduced carbon footprint, primarily by removing the need for traditional steel rebar and mesh, where 50 kg of steel fibres can often do the work of 100 kg+ of traditional rebar. Eliminating this expensive material also reduces labour and maintenance costs.

In his latest research, Adanu has explored an unexpected alternative fibre reinforcement material that would decrease costs further as it would otherwise go to landfill: human hair (*Eng. Res. Express* **7** 015115). Adanu took waste hair from barbershops in Debre Tabor (with permission, of course), and added small amounts of it in different quantities to standard concrete mixes. "It's not biodegradable, it's not compostable, but as a fibre reinforcement material, we found that using 1–2% human hair improves the concrete's tensile strength, compressive strength, cracking resistance and reduces shrinkage," says Adanu. "It makes concrete more clean and sustainable, and because it improves the quality of the concrete, it reduces cost at the same time."

Research like Adanu's, involving experimentation with local materials, has been the driving force for innovation in construction for millennia. From the ancient Neolithic practice of boosting mudbricks' strength by adding local straw, to the Romans using volcanic dust as high-quality cement for concrete constructions like the Pantheon in Rome – a structure that still stands to this day, with its 43.3-m diameter non-reinforced concrete dome remaining the largest in the world. But testing one material at a time is no longer the only way.

Taking a more modern, wide-ranging approach, a team of researchers led by Soroush Mahjoubi and Elsa Olivetti of Massachusetts Institute of Technology (MIT), recently mined the cement and concrete literature, and a database of over one million rock samples, looking for cement ingredient substitutes (*Communications Materials* **6** 99). The study not only confirmed the potential of the well-known alternatives fly ash and metallurgic slags, but also various biomass ashes like the bamboo leaf ash Adanu investigated, as well as rice husk, sugarcane bagasse, wood, tree bark and palm oil fuel ashes.

The meta-review in addition identified various other waste materials with high potential. These include construction and demolition wastes (ceramics, bricks, concrete), waste glass, municipal solid waste incineration ashes, and mine tailings (iron ore, copper, zinc), as well as 25 igneous rock types that could significantly reduce cement's carbon impact.

AI to the rescue

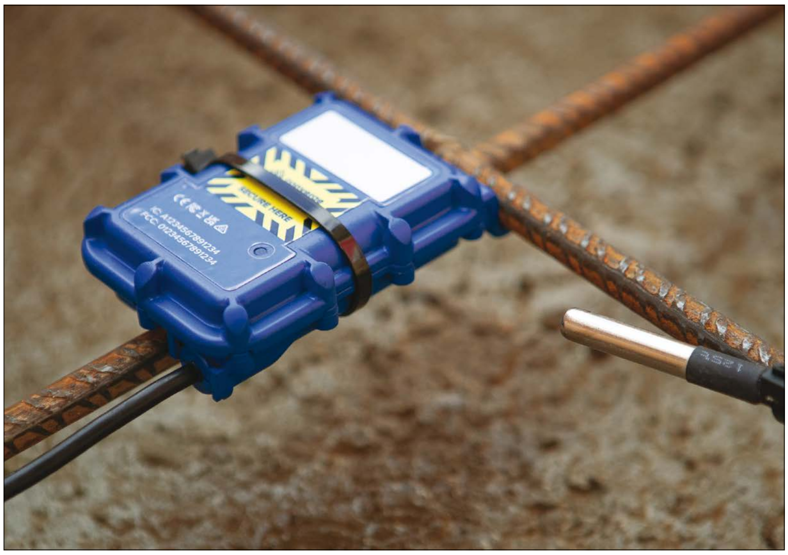
Although a number of these alternative concrete materials have been known for some time, they have struggled to make an impact, with very few being used to partially replace regular cement in ready-mix concretes. Getting construction companies or concrete contractors to give them a try is no simple task.

"Concrete contractors are used to using certain mixes for certain jobs at certain times of the year, so they can plan a site and project based on how those materials are going to behave," says Toogood. "Newer mixes act slightly differently when fresh," she adds, which makes life tricky for those running a construction site, where concrete that behaves in a predictable manner is critical so that things run smoothly and efficiently.

Two physicists – Raphael Scheps and Gideon Farrell – aim to build this trust in low-carbon alternatives through their UK construction technology company Converge. Starting out using sensors to measure the real-time performance of different mixes of concrete *in situ*, they have built one of the world's largest datasets on the performance of concrete.

They can now apply an AI model underpinned by physics principles. The program simulates the physical and chemical interactions of different components to predict the performance of a vast number of concrete mixes in a wide range of situations to a high level of accuracy. And this is key, as it builds trust to experiment with lower-carbon mixes. "With projects in the UK and Australia, we've helped people tweak the mix that they're using and achieve quite major carbon savings," says Scheps. "Anywhere from 10% all the way up to 44%."

Currently used to recommend existing cost-saving concrete recipes, Scheps sees Converge's AI model becoming more sophisticated over time. "As it starts to uncover the real fundamental physics-based rules for what drives concrete chemistry, our model will make projections for entirely new materials," he enthuses.



Converge

Converge

Watch and learn UK construction technology company Converge uses sensors to measure the real-time performance of different mixes of concrete *in situ*, then adds the data to its AI program to model untested concrete mixes. (top) Signal Long Range is Converge's LoRaWAN-enabled, fully embedded concrete-monitoring sensor for large-scale construction. (bottom) Installation of Converge's Helix system at HS2 Old Oak Common – a long-range, reusable concrete-monitoring solution.

Also exploring the power of AI to optimize concrete production is US company Concrete.ai. Like Converge, Concrete.ai was born from the idea of applying physics principles to optimize traditional materials and industries; specifically, how AI can be used to reduce the carbon footprint of concrete. And also like Converge, the company's technology rests on one of the world's largest concrete databases, consisting of vast amounts of different recipes and materials, alongside their associated performances.

Trained on this dataset, Concrete.ai's generative AI model creates millions of possible mix designs to identify the optimal concrete recipe for any particular application. "The main difference between a solution like Concrete.ai's and general models like ChatGPT or Gemini is that our goal is really to create recipes that don't exist yet," explains chief technology officer and co-founder

Mathieu Bauchy. "Popular large language models regurgitate what they have been trained on and tend to hallucinate, whereas our model discovers new recipes that have never been produced before without breaking the laws of physics or chemistry, and in a reliable way."

Bauchy sees Concrete.ai's role as a bridge between concrete producers keen to cut their costs and carbon footprint, and innovators like Adanu or the MIT group exploring new low-carbon concrete materials who are unable to demonstrate the performance of these materials in real-world scenarios and at scale.

Circular benefits

It is perhaps apt that the industry most in need of AI insights from the likes of Converge, Concrete.ai and their growing number of competitors is the AI industry itself. New data centres being used to train, deploy and deliver AI applications and services are the cause of a huge spike in the greenhouse gas emissions of tech giants such as Google, Meta, Microsoft and Amazon. And one of the biggest contributors to those emissions is the concrete from which these hyperscale facilities are built.

This is the reason Meta recently partnered with concrete maker Amrize to develop AI-optimized concrete. For Meta's new 66 500 m^2 data centre in Rosemount, Minnesota, the partners applied Meta's AI models and Amrize's materials-engineering expertise to deliver concrete that met key criteria including high strength and low carbon content, as well as practical performance characteristics like decent cure speed and surface quality. The partners estimate that the custom mix will reduce the total carbon footprint of this concrete by 35%.

"There is an interesting synergy between concrete and AI," says Bauchy. "AI can help design greener concrete, and on the other hand, concrete can be used to build more sustainable data centres to power AI." With other tech giants exploring AI's potential in reducing the carbon footprint of the concrete they use too, it may well be that the very places in which AI is developed become the testbeds for AI-derived sustainable green concrete solutions.

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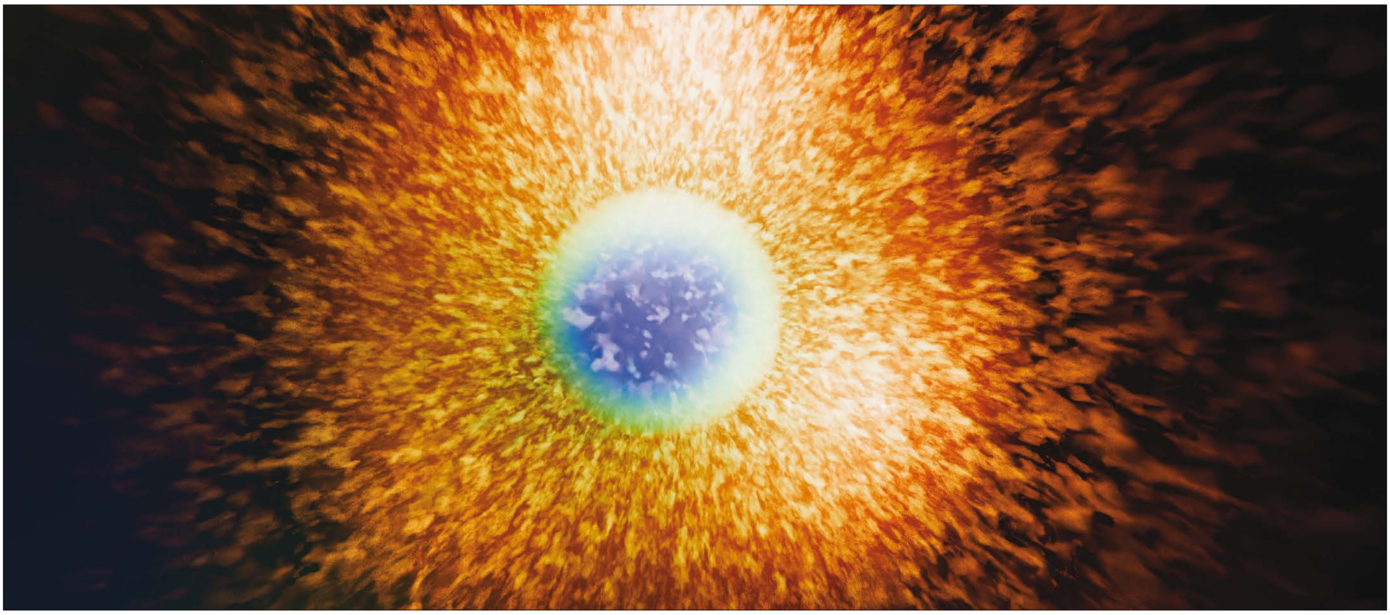
Feedback loop The Google Hyperscale Data Center for AI and Sustainable Energy opened in Winschoten, Netherlands, in November 2025. The massive growth in AI is leading to many more of these huge structures, and though the electricity they run on is increasingly from renewable sources, the concrete from which they are built is decidedly less green. But AI is also potentially the best resource we have to reduce the carbon cost of concrete.

Focusing on fusion

Harnessing the full potential of nuclear fusion could mean access to limitless amounts of clean energy. Among those working towards that goal is plasma physicist **Debbie Callahan**, chief strategy officer at Focused Energy. She talks to Hamish Johnston about the start-up's technology, her move from a national laboratory to industry, and career opportunities in the fusion sector



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With the world's energy demands increasing, and our impact on the climate becoming ever clearer, the search is on for greener, cleaner energy production. That's why research into fusion energy is undergoing something of a renaissance.

Construction of the International Thermonuclear Experimental Reactor (ITER) in France – the world's largest fusion experiment – is currently under way, while there are numerous other large-scale facilities and academic research projects too. There has also been a rise in the number of smaller commercial companies joining the race.

One person at the forefront of fusion research is Debbie Callahan – a plasma physicist who spent 35 years working at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in the US. She is now chief strategy officer at Focused Energy, a laser-fusion firm based in Germany and California, which is trying to generate energy from the laser-driven fusion of hydrogen isotopes.

Callahan talked to *Physics World*'s Hamish Johnston about working in the fusion sector, Focused Energy's research and technology, and the career opportunities available. The following is an edited extract of their conversation, which you can hear in full on the *Physics World Weekly* podcast of 22 January.

How does NIF's approach to fusion differ from that taken by magnetic confinement facilities such as ITER?

To get fusion to happen, you need three elements that we sometimes call the triple product. You need a certain amount of density in your plasma, you need temperature, and you need time. The product of those has to be over a certain value.

Magnetic fusion and inertial fusion are kind of the opposite of each other. In a magnetic fusion system like ITER, you have a low-density plasma, but you hold it for a long time. You do that by using magnetic fields that trap the plasma and keep it from escaping.

In inertial fusion – like at NIF – it's the opposite. You don't hold the plasma together at all, it's only held by its own inertia, and you have a very high density for a short time. In both cases, you can make fusion happen.

What is the current state of the art at NIF, in terms of how much energy you have to put in to achieve fusion versus how much you get out?

To date, the best shot at NIF – by which I mean an individual, high-energy laser bombardment of the target capsule – occurred during an experiment in April 2025, which had a target gain of about 4.1. That means that they got out 4.1 times the amount of energy that they put in. The incident laser energy for those shots is around two megajoules, so they got out about eight megajoules.

This is a tremendous accomplishment that's taken decades to get to. But to make inertial fusion energy successful and use it in a power plant, we need significantly higher gains of more like 50 to 100.

Can you explain Focused Energy's approach to fusion?

Focused Energy was founded in July 2021, and has offices in the US and Germany. Just a month later, we achieved fusion ignition, which is when the fusion fuel becomes hot enough for the reactions to sustain themselves through their own internal heating (it is not the same as gain).

At NIF lasers are fired into a small cylinder of gold or depleted uranium and the energy is converted into X-rays, which then drive the capsule. It's what's called laser indirect drive. At Focused Energy, however, we're directly driving the capsule. The laser energy is put

Lawrence Livermore National Laboratory/Damien Jemison

Captured beams The target chamber of the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory.

Listen to an extended version of this interview

Focused Energy

Fusion adopter Debbie Callahan worked at NIF for 35 years before becoming chief strategy officer at Focused Energy.

directly on the capsule, with no intermediate X-rays.

The advantage of this approach is that converting laser energy to X-rays is not very efficient. It makes it much harder to get the high target gains that we need. At Focused Energy, we believe that direct drive is the best option for fusion energy to get us to a gain of over 50.

So is boosting efficiency one of your key goals to make fusion practical at an industrial level?

Yes, exactly. You have to remember that NIF was funded for national security purposes, not for fusion energy. It wasn't designed to be a power plant – the goal was just to generate fusion energy for the first time.

In particular, the laser at NIF is less than 1% efficient but we believe that for fusion power generation, the laser needs to be about 10% efficient. So one of the big thrusts for our company is to develop more efficient lasers that are driven by diodes – called diode pump solid state lasers.

Can you tell us about Focused Energy's two technologies called LightHouse and Pearl Fuel?

LightHouse is our fusion pilot plant. When operational, it will be the first power plant to produce engineering gain greater than one, meaning it will produce more energy than it took to drive it. In other words, we'll be producing net electricity.

For NIF, in contrast, gain is the amount of energy out relative to the amount of laser energy in. But the laser is very inefficient, so the amount of electricity they had to put in to produce that eight megajoules of fusion energy is a lot.

Meanwhile, Pearl is the capsule the laser is aimed at in our direct drive system. It's filled with deuterium–tritium fuel derived from sea water and lithium.

How do you develop the capsule to absorb the laser energy and give as much of it to the fuel as possible?

The development of the capsule for a fusion power plant is quite complicated. First, we need it to be a perfect sphere so it compresses spherically. The materials also need to efficiently absorb the laser light so you can minimize the size of that laser.

You have to be able to cheaply and quickly mass produce these targets too. While NIF does 400 shots per year, we will need to do about 900 000 shots a day – about 10 per second. We'll also have to efficiently remove the exploded target material from the reactor chamber so that it can be cleared for the next shot.

It's a very complicated design that needs to bring together all the pieces of the power plant in a consistent way.

When you are designing these elements, what plays a bigger role – computer simulations or experiments?

Computer simulations play a large part in developing these designs. But one of the lessons that I learned from NIF was that, although the simulation codes are state of the art, you need very precise answers, and the codes are not quite good enough – experimental data play a huge role in optimizing the design. I expect the same will be true at Focused Energy.

A third factor that's developing is artificial intelligence (AI) and machine learning. In fact, at Livermore, a project working on AI contributed to achieving gain for the first time in December 2022. I only see AI's role in fusion getting bigger, especially once we are able to do higher repetition rate experiments, which will provide more training data.

What intellectual property (IP) does Focused Energy have in addition to that for the design of the Pearl target and the LightHouse plant?

We also have IP in the design of the lasers – they are not the same lasers as used at NIF. And I think there'll be a lot of IP around how we fabricate the targets. After all, it's pretty complicated to figure out how to build 900 000 targets a day at a reasonable cost.

We'll see a lot of IP coming out of this project in those areas, but there's also the act of putting it all together. How we integrate these things in order to make a successful plant is important.

What are the challenges of working with deuterium and tritium as materials for fusion?

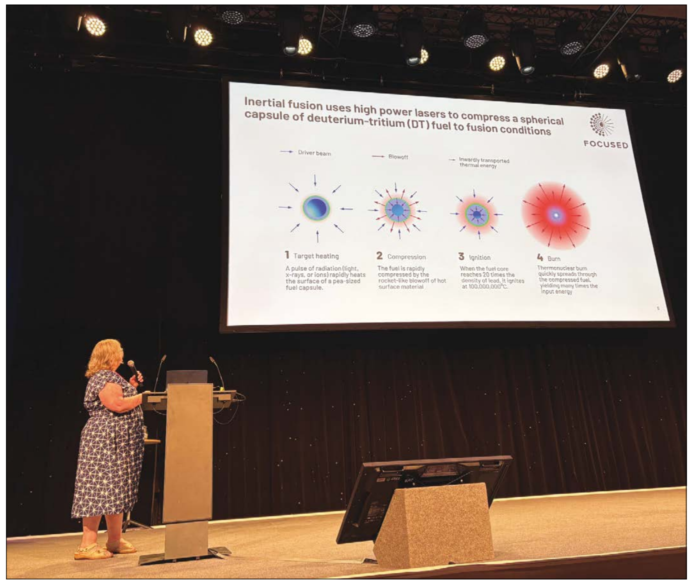
We chose deuterium and tritium because they are the easiest elements to fuse, and have been successfully demonstrated as fusion fuel by NIF.

Deuterium can be found naturally in sea water, but getting tritium – which is radioactive – is more complicated. We breed it from lithium. Our reactor designs have lithium in them, and the neutrons from the fusion reactions breed the tritium.

Making sure that we have enough tritium, and figuring out how to extract that material to use it for future shots, is a big task. We

Focused Energy

Rejuvenating nuclear A rendering of Focused Energy's proposed fusion power plant at the Biblis fission power plant in Germany, which was shut down in 2011.



Focused Energy

Active collaboration Debbie Callahan presenting the work of Focused Energy at the IEEE Pulsed Power and Plasma Science Conference in Berlin in June 2025.

have to be able to breed enough tritium to keep the plant going.

To work on this, we have a collaboration funded by the US Department of Energy to work with Savannah River National Lab in South Carolina. They have a lot of expertise in designing these tritium-extraction systems.

How will you capture the heat from the deuterium–tritium fusion reaction?

We will use a conventional steam cycle to convert the heat into electricity. It's funny – we'll have this very hi-tech way of producing heat, but at the end of the day, we will use a traditional system to produce the electricity from that heat.

So what's the timeline on development?

Our plan is to have a pilot plant up by the end of the 2030s. It's a fairly aggressive timeline given the things that we have to do. But that's part of being a start-up – we have to take some risks and try to move quickly to achieve our goal.

To help that we have, in my view, a superpower – we have one foot in Europe and one foot in the US. There are a lot of opportunities between the two continents to partner with other companies, universities and governments. I think that makes us strong because we have access to some of the best talent from around the world.

How does working at Focused Energy compare with life as an academic at Lawrence Livermore?

There are a lot of similarities. My role now is to bring the knowledge and skills I learned at NIF to Focused Energy, so it's been a natural transition.

In fact, there was a lot of pressure working at NIF. We were trying to move very quickly, so it's actually very similar to working in a start-up like Focused Energy.

One big difference is the level of bureaucracy. Working for a government-funded lab meant there were lots of rules and paperwork, which takes up your time and you don't always see the value in it.

In contrast, working for a small start-up means we can move more quickly because we don't have as many of those kinds of constraints. Personally, I find that great because it leaves more time for the fun and interesting things – like trying to get fusion on the grid.

Are you still involved in academic research in any way?

As a firm, we are still out there collaborating with academics. Last year, for example, we gave four separate presentations at the American Physical Society Division of Plasma Physics meeting.

I feel very strongly about peer review. Of course, publishing isn't our number one priority, but we need feedback from others. We're trying to do something that no-one's done before, so it's important to have our colleagues give us feedback on what we're doing, point out mistakes we're making or things we're forgetting.

Working with universities and national labs in both Europe and the US is vital. Communicating with others in the field is important for us to get to where we want to go.

And of course, being an active part of the fusion community is good for recruitment too. We regularly give presentations at conferences that students attend. We meet those students and they learn about our work – and they might be future employees for our company.

What's your advice for early-career physicists keen on joining the fusion industry?

There are so many opportunities right now, especially compared to the start of my career when the work was mainly just at universities or national labs. Nowadays, there are a lot of companies in the sector. Not all of them will survive because there's only so much money, but there are still lots of opportunities. If you're interested in fusion energy, go for it.

The field is always developing. There's new stuff happening every day – and new problems. So if you like problem-solving, it's great, especially if you want to do something good for the world.

There are also opportunities for people who are not plasma physicists. At Focused Energy we have people across so many fields – those who work on lasers, others who work on reactor design, some developing the AI and machine learning, and those who work on target physics, like me. To achieve fusion energy, we need physicists, engineers, mathematicians and computer scientists. We need researchers, technicians and operators. There's going to be tremendous growth in this sector.

Hamish Johnston is an online editor of *Physics World*

A physicist's journey into nuclear energy

Early-career physicist **Natasha Khan** talks about her route to becoming a nuclear safety engineer – a journey that includes job rejections, the charity sector and nuclear awards

Natasha Khan

Rising star Natasha Khan collecting her Graduate of the Year, UK Nuclear Skill award in 2024.

When I started my physics degree, I knew it could open the door to a range of career opportunities, but I wasn't sure what path it would take me down. In the end, it was the optional modules that encouraged my interest in nuclear energy physics, steering me towards my current job as a nuclear safety engineer.

When I was looking at university degrees, I thought about studying chemical engineering, but my A-level physics teacher inspired me to consider physics instead. I'd always been fascinated with the subject, and enjoyed maths (and a challenge) too, so I thought why not give it a go.

I went on to study physics at the University of Liverpool, graduating in 2021. I absolutely loved the city and would highly recommend it to anyone considering physics – or any degree, for that matter. The campus is fantastic and Liverpool is an amazing place to be a student.

My undergraduate experience was incredibly rewarding. I met some of my closest friends and had countless memorable adventures. While the course was challenging at times, I have no regrets about choosing physics. I particularly enjoyed being able to pick specialist optional modules as it meant I could follow my interest in applied physics with topics such as nuclear power and medical physics.

Making a difference

In my final year, I started doing the obligatory job applications for those wanting to go into industry. But after receiving some rejections, I decided to explore an opportunity outside of science and ended up working for nearly a year in the charity sector as a Climate Action intern. There I undertook research projects related to decolonization in international development, and anti-racism and social justice, supporting the delivery of international development programmes.

While my time at Climate Action was rewarding and worthwhile, I wanted to move back into science and use my degree. Nuclear physics had been an area of interest for me since school, and my modules at university had encouraged that, so I turned my attention to the nuclear energy sector. Having worked for a charity, I was keen to find an organization whose values aligned with mine. Employee-owned engineering, management and development consultancy, Mott MacDonald, caught my eye, with its commitment to net zero, social outcomes and the UN's Sustainable Development Goals.

I joined the company's three-year graduate scheme and, although I didn't have any direct experience in safety, was offered a graduate nuclear safety position. It is a great role that ties in skills from my degree and my interest in nuclear while still presenting challenges and an opportunity to learn.

After two years at Mott MacDonald, I won Graduate of the Year at the UK Nuclear Skills Awards 2024. My colleagues had kindly nominated me, recognizing my dedication and drive, and the contribution I'd made to the organization. This opportunity was highly valuable for me and elevated my profile not only at Mott MacDonald but also within the sector. Then, after only two and half years in the graduate scheme, I was promoted to my current position of nuclear safety engineer.

My role focuses on developing nuclear safety cases with the guidance and support of our experienced team. The work involves analysing potential hazards and risks, outlining safety measures, and presenting a structured, evidence-based argument that the facility is safe for operation. I've worked on a variety of different projects including small modular reactors, nuclear medicine and flood alleviation schemes.

A typical day for me involves project meetings, writing safety reports, conducting

US Nuclear Regulatory Commission

Wealth of opportunity Natasha Khan believes that now is a great time to join the nuclear industry.

hazard identification studies, and reviewing documents. A key aspect of the work is identifying, assessing and effectively controlling all project-related risks.

Beyond my technical role at Mott MacDonald, I am also part of committees for our internal Women in Nuclear and Europe and UK Advancing Race and Culture networks. These positions allow me to contribute to a range of equality, diversity and inclusion (EDI) initiatives. Creating an inclusive environment is important to allow people the space to be authentically themselves, share and bring diverse perspectives and feel psychologically safe. This is a big driver for me – by supporting equity and equal opportunities, I am helping ensure others like me have role models in the sector.

I would encourage other physics students to explore a career in the nuclear industry

A nuclear skillset

Physics plays a crucial role in nuclear safety by providing the fundamental principles underlying nuclear processes. Studying nuclear physics at university has helped me understand and analyse reactor behaviour, radiation effects and potential hazards. This knowledge forms the basis for designing nuclear facility safety systems, for the protection of the workforce, environment and general public.

Throughout my degree, I also developed transferable skills such as analytical thinking, logical problem-solving and teamwork, all of which I apply daily in my role. As a safety-case engineer, I work as part of a team, and collaborate with specialists across fields, including process engineering, mechanical engineering and radioactive waste management. My ability to work effectively in teams and maintain strong interpersonal relationships has been key to success in my role.

Applying my research and scientific report writing skills I developed at university, I can identify relevant information for safety-case updates, and present safety claims, arguments and evidence in a way that is understandable to a broad, non-specialist audience.

I also mentor and support more junior colleagues with various project and non-project related issues. Skills like critical thinking and the ability to tailor my communication style directly influence how I approach my work and support others.

I would encourage other physics students to explore a career in the nuclear industry. It offers a broad range of career paths, and the opportunity to contribute to some of the most diverse, exciting and challenging projects within the energy sector. You don't need an engineering background to have a career in nuclear – there are many ways to contribute including beyond the technical route. As physicists we have a wide range of transferable skills, often more than we realize, making us highly adaptable and valuable in this sector.

It's an incredible time to join the nuclear industry. With advancements like Sizewell C, small modular reactors, and cutting-edge medical nuclear-research facilities, there's a wealth of diverse projects happening right now to get involved in. I hadn't planned on a career in nuclear safety, but honestly, I'm really glad my path led this way. I am passionate about driving innovative nuclear solutions, and support progress towards reduced emissions and the global transition to net zero.

While I may be early on in my nuclear career, I have already worked on some interesting projects and met fantastic people. Now, I'm going through a structured training programme at Mott MacDonald to help me achieve chartership status with the Institute of Physics. I look forward to seeing what the future has to offer.

Natasha Khan is a nuclear safety engineer at Mott MacDonald

Ask me anything: Katie Perry

Katie Perry is chief executive of the Daphne Jackson Trust, which supports people who want to get back into research after a career break. She studied physics at the University of Surrey in the UK, staying on there to do a PhD. While at Surrey, she worked with the nuclear physicist Daphne Jackson, who was the first female physics professor in the UK. Perry later worked in science communication – both as a science writer and in public relations. She is currently chief executive of the Daphne Jackson Trust – a charity that supports returners to research careers after a break of at least two years for family, caring or health reasons. It offers fellowships to support people to overcome the challenges of returning, ensuring that their skills, talent, training and career promise are not lost.

Katie Perry

Changing lanes Katie Perry believes that you need to be adaptable as today's career paths tend to be highly non-linear.

What skills do you use every day in your job?

One of the most important skills is multitasking and working in an agile and flexible way. I'm often travelling to meetings, conferences and other events so I have to work wherever I am, whether it's on a train, in a hotel or at the office. How I work reminds me of a moment I had towards the end of my physics degree when suddenly everything I'd been learning seemed to fit together; I could see both the detail and the bigger picture. It's the same now. I have to switch quickly from one project or task to another, while keeping oversight of the overall direction and operation of the charity.

I am a strong advocate for part time and flexible working, not just for me, but for all my staff and the Daphne Jackson fellows. As a manager, a key skill is to see the person and their value – not just the hours they are working. Communication and networking skills are also vital as much of my role involves developing collaborations and working with stakeholders. I could be meeting a university vice chancellor, attending a networking reception, talking to our fellows or ensuring the trust complies with charity governance – all in one day.

What do you like best and least about your job?

I love my current role, and at the risk of sounding a little cheesy, it's because of the trust's amazing staff and the inspiring returners we support. The fact that I knew Daphne Jackson means that leading the organization is personal to me. I'm always blown away by how inspirational, dedicated, motivated and talented our fellows are and I love supporting them to return to successful research careers. It's a privilege to lead the charity, helping to understand the challenges and barriers that returners face – and finding ways to overcome them.

Leading a small charity requires a broad set of skills. I enjoy the variety but it's a challenge because you're not so much a "chief executive officer" as a "chief everything officer". I don't have huge teams of people to help me with, say, human resources, finance or health and safety, which makes it struggle to do them as well as I'd like. It's therefore important to have a good work-life balance, which is why I recently took up golf. I've yet to have a work meeting while out practising my swing, but one day my diary might say I'm "on a course"!

> I'd tell my younger self to network like crazy. You never know who you might meet or what making new connections can lead to

What do you know today, that you wish you knew when you were starting out in your career?

If I could go back in time, I'd tell myself – like I now tell my daughter – that it's fine not to have a defined career path or plan. Sure, it helps to have an idea of what you want to do, but you have to live and work a little to discover what you like and – more importantly – don't like. Careers these days are highly non-linear. Unexpected life events happen so you have to adapt, just as our Daphne Jackson fellows have done.

If someone had said to me in my 20s, when I was planning a career in science communication, that I'd be a charity chief executive I wouldn't have believed them. But here I am running a charity founded in memory of the physicist who was such a great mentor to me during my PhD. When one door closes, a window often opens – so don't be afraid to take set off in a new direction. It can be scary, but it's often worth the effort.

I'd also tell my younger self to network like crazy. So many opportunities have opened up because I love speaking to people. You never know who you might meet at events or what making new connections can lead to. Finally, I wish I'd known that "impostor syndrome" will always be with you – and that it's okay to feel that way provided you recognize it and manage it. Chances are, you may never defeat it completely.

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Squeaky shoes and childcare physics

Michael Banks picks his favourite stories and quotes from the weird and wonderful world of physics

If you have ever watched a basketball game, you'll know that along with the sound of the ball being bounced, there is also the constant squeaking of shoes as the players move across the court. Physicists in France, Israel, the UK and the US have now recreated the phenomenon in a lab and discovered that the squeaking is due to a previously unseen mechanism (*Nature* **650** 841). In the new study, Katia Bertoldi from the Harvard John A Paulson School of Engineering and Applied Sciences and colleagues slid a basketball shoe and a rubber sample across a smooth glass plate and used high-speed imaging and audio measurements to analyse the squeak.

Previous research looking at the effect suggested that "pulses" are created when two materials "stick and slip", but those studies focused on slow movements, which do not create squeaks. Bertoldi and team found that the noise is not caused by random stick-slip events, but rather deformations of the rubber sole pulsing in bursts, or rippling, across the surface. Small parts of the sole change shape and lose and regain contact with the surface, with the "ripple" travelling at near supersonic speeds. The pitch of the squeak even matches the rate of the "bursts", which is determined by the stiffness and thickness of the shoe sole. The authors also found that if a soft surface is smooth, the pulses are irregular and produce no sharp sounds, whereas ridged surfaces – like the grip patterns on sports shoes – produce consistent pulse frequencies, resulting in a high-pitched squeak.

"These results bridge two fields that are traditionally disconnected: the tribology of soft materials and the dynamics of earthquakes," says Shmuel Rubinstein from Hebrew University. "Soft friction is usually considered slow, yet we show that the squeak of a sneaker can propagate as fast as, or even faster than, the rupture of a geological fault, and that their physics is strikingly similar."

Shutterstock/SeventyFour

Pip and squeak The noise of squeaky basketball shoes is down to the base of the shoe forming wrinkles that travel at near supersonic speeds.

If you see a Black woman, don't make assumptions

Space scientist **Maggie Aderin**, who is chancellor of the University of Leicester, was discussing the common misconceptions she faces as a Black woman, saying it is important to break stereotypes that exist in science. (Source: BBC)

It was one of the most thrilling weeks of my life

US novelist **Nova Jacobs** writes murder mysteries set in the world of physics. For her second novel – *In the Stars Turned Inside Out* – she spent a week at CERN in Switzerland trailing particle physicists. (Source: *APS Physics*)

The physics of "unethical" daycare

Anyone with kids in daycare, or nursery, will know the constant battle with germs and illness. That dilemma faced mathematician Lauren Smith from the University of Auckland, who had two children at a "wonderful daycare centre" who often succumbed to illness. As many parents juggling work and parenting will understand, Smith frequently faced the issue of whether her kids are well enough to attend daycare. Smith then thought about how an unethical daycare centre might take advantage of this to maximize its profits – under the assumption that if there are not enough children attending (who still pay) then staff get sent home without pay, and also don't get sick pay themselves.

"It occurred to me that a sick kid attending daycare could actually be financially beneficial to the centre, while clearly being a detriment to the wellbeing of the other children as well as the staff and the broader community," Smith told *Physics World*. For a hypothetical daycare centre that is solely focused on making as much money as possible, Smith realized that full attendance of sick children is not optimal financially as this requires maximal staffing at all times, whereas zero attendance of sick children does not give an opportunity for the disease to spread such that other children are then sent home.

But in between these two extremes, Smith thought there should be an optimal attendance rate so that the disease is still able to spread and some children – and staff – are sent home.

Using the so-called Susceptible-Infected-Recovered model for 100 children, a teacher to child ratio of 1:6 and a recovery rate from illness of 10 days, Smith found that a more infectious disease requires fewer ill children to attend to spread it around, and so it is possible to keep more of them – and importantly staff – at home while still making sure it still spreads to non-infected kids (arXiv:2601.20123). For a measles outbreak with a basic reproductive number of 12–18, for example, the model resulted in a potential staff saving of 90 working days, whereas for seasonal flu with a basic reproductive rate of 1.2 to 1.3, the potential staff savings is 4.4 days. Smith writes in the paper that the work is "not intended as a recipe for unethical daycare centre" but is rather to illustrate the financial incentive that exists for daycare centres to propagate diseases among children, which would lead to more infections of at-risk populations in the wider community.

Michael Banks is news editor of *Physics World*

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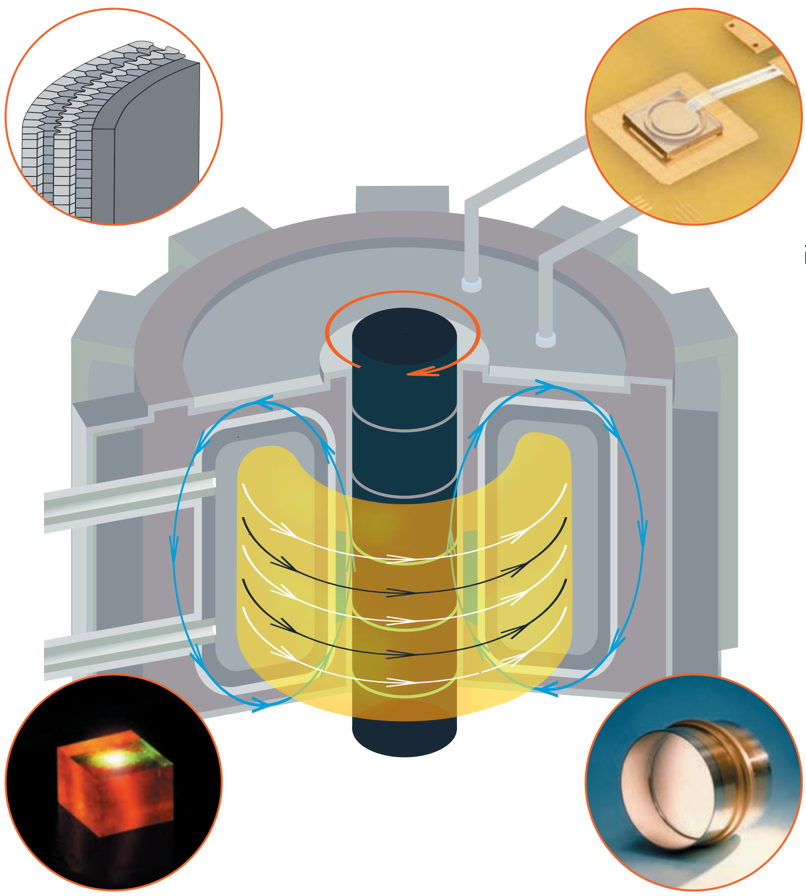

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